PRACTICAL HYDRAULICS.

PRACTICAL HYDRAULICS:

A SERIES

OF

RULES AND TABLES

FOR

THE USE OF ENGINEERS, ETC., ETC.

BY

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PREFACE TO THE SECOND EDITION

In preparing a Second Edition of 'Practical Hydraulics' considerable alterations and additions have been made To facilitate reference, the work has been divided into Chapters, additional Rules for Culverts and other subjects have been given, including several new Tables, and an increased number of Illustrations These alterations were so considerable, that it was found necessary to re-write the whole, and thus opportunity was given to introduce much new and valuable information, which, it is hoped, will increase the usefulness of the work

Bath, *July*, 1870

PREFACE TO THE FIRST EDITION

The reader must not expect, in this little book, an exhaustive treatise on Hydraulics, many such have been written, and they leave little or nothing to be desired This work consists of a series of Rules and Tables, giving unusual facility for the solution of questions which occur in the daily practice of Engineers

For the two leading questions—the Discharge of Pipes, and of Open Channels—two sets of Tables are given, the reason for

which may not be obvious; but it is impossible to give Tables combining extreme facility with extreme accuracy for low heads, and the author has therefore given two Tables, one giving accurate results in all ordinary cases with the least possible labour, and the other giving, with more labour, exact results in extreme cases.

For the most part the Rules and Tables have been long used in an extensive practice, and the principal reason for publishing them is the author's desire that the profession from which he has retired may have the benefit of Tables, &c., which for many years have been very useful to himself.

EASEDALE, GRASMERE,
July, 1867.

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PRACTICAL HYDRAULICS.

CHAPTER I.

DISCHARGE OF APERTURES, PIPES, &c

(1) "*Velocity of Efflux*"—The velocity with which water issues from the side of a vessel, as at A, Fig 1, is the same as that of a body falling freely by gravity from the height H, or the distance from the centre of the orifice to the surface of the water This velocity is given by the rule —

$$V = \sqrt{H} \times 8$$

In which H = the height or head of water in feet, and V = the velocity in feet per second From this we may obtain another rule giving the discharge in gallons, which becomes —

$$G = \sqrt{H} \times d^2 \times 16\ 3$$

In which H = the head of water in feet, d = the diameter of the orifice in inches, and G = gallons discharged per minute Table 1 has been calculated by this rule.

These rules give the *theoretical* velocity and discharge for application to practice, they may require some modification to adapt them to the particular form of the orifice

(2) "*Discharge by an Orifice in a Thin Plate* —It has been found by experiment that, when the discharging orifice is made in a thin plate, the converging currents of water approaching the aperture cause a *contraction* in the issuing stream, so that instead of a parallel or cylindrical jet, it becomes a conical one of the form shown by Fig 2, the greatest contraction being at

TABLE 1.—Of the THEORETICAL DISCHARGE of WATER by ROUND APERTURES of various DIAMETERS, and under Different Heads of Water Pressure

Diam. in Inches	Head of Water in Inches.																
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24
	Discharge in Gallons per Minute																
1	4·7	6 6	8 1	9 4	10 5	11 5	12 4	13 3	14 1	14 8	16 2	17 6	18 8	19 9	21	22	23
2	18 8	26 4	32 4	37 6	42 0	46 0	49 6	53 2	56 4	59 2	64 8	70 4	75 2	79 6	84	88	92
3	42 2	59 4	72 9	84 6	94 5	103	112	120	127	133	146	158	169	179	189	198	207
4	75 2	106	130	150	168	184	198	213	225	237	259	281	301	318	336	352	368
5	117	165	203	235	262	287	310	332	352	370	405	440	470	497	525	550	575
6	169	237	291	338	378	414	446	479	507	533	583	663	677	716	756	792	828
7	230	310	397	460	514	563	607	652	691	725	794	862	921	975	1029	1078	1127
8	301	422	518	601	672	736	793	851	902	947	1037	1126	1203	1273	1344	1408	1472
9	381	534	656	761	850	931	1006	1077	1142	1199	1312	1425	1523	1612	1701	1782	1863
10	470	660	810	940	1050	1150	1240	1330	1411	1480	1620	1760	1880	1990	2100	2200	2300
12	676	952	1168	1353	1512	1656	1785	1915	2030	2134	2333	2534	2707	2865	3024	3170	3312
14	920	1211	1588	1842	2058	2254	2430	2606	2764	2901	3175	3450	3684	3900	4116	4312	4508
16	1203	1690	2074	2406	2688	2944	3174	3405	3610	3789	4147	4506	4813	5094	5376	5632	5888
18	1523	2139	2624	3045	3402	3726	4018	4309	4568	4795	5249	5702	6091	6447	6804	7128	7452
20	1880	2640	3240	3760	4200	4600	4960	5320	5640	5920	6480	7040	7520	7960	8100	8800	9200
22	2275	3194	3920	4550	5082	5566	6002	6437	6824	7163	7841	8518	9099	9632	10164	10648	11132
24	2704	3808	4672	5414	6048	6624	7140	7660	8120	8536	9332	10136	10829	11460	12096	12680	13248
30	4230	5940	7290	8460	9450	10350	11160	11970	12690	13320	14580	15840	16920	17910	18900	19800	20700
Velocity in feet per second	2 32	3 275	4 01	4 63	5 18	5 67	6 13	6 55	6 95	7 32	8 03	8 67	9 27	9 83	10 36	10 87	11 35

the point C, whose distance from the plate is half the diameter of the orifice, and its diameter .781, that of the orifice being 1. The form from B to C may be taken as a curve, whose radius is 1.22 times the diameter of the orifice.

Now, the foregoing rule gives the maximum velocity, or that at the point of greatest contraction C, and if the diameter be taken there, the rules would give the true velocity and discharge without correction. But it is obvious that the velocity at the aperture itself (or at B) would be less than at C in the ratio of the respective areas at the two points, or as 1^2 to $.781^2$ or 1 to .615, and in that case, the diameter being taken at B, the velocity there would become $V = \sqrt{H} \times 8 \times .615$ and the discharge $G = \sqrt{H} \times d^2 \times 16.3 \times .615$. From this we get for apertures in a thin plate, the rules:—

$$G = \sqrt{H} \times d^2 \times 10$$

$$H = \left(\frac{G}{d^2 \times 10}\right)^2$$

$$d = \left(\frac{G}{\sqrt{H} \times 10}\right)^{\frac{1}{2}}$$

Thus, with 3 inches diameter and 16 feet head, the discharge would be $\sqrt{16} \times 3^2 \times 10$ or $4 \times 9 \times 10 = 360$ gallons per minute. The head for 150 gallons per minute with 2 inches diameter $= \left(\frac{150}{4 \times 10}\right)^2 = 14.06$ feet, and the diameter for 200 gallons per minute with 20 feet head would be $\left(\frac{200}{4.47 \times 10}\right)^{\frac{1}{2}} =$ 2.11 inches, &c., &c.

(3.) "*Discharge by Short Tubes.*—When the aperture is of considerable thickness or has the form of a short tube not less in length than twice the diameter, the amount of contraction is found to be less and the discharge greater, than with a thin plate. Fig. 3 shows a tube 1 inch diameter and 2 inches long, the greatest contraction is in that case .9 inch diameter, and its pro-

portional area $\cdot 9^2 = \cdot 81$, or say $\cdot 8$ of the area of the tube. For short tubes therefore the rules become:—

$$G = \sqrt{H} \times d^2 \times 13$$

$$H = \left(\frac{G}{d^2 \times 13}\right)^2$$

$$d = \left(\frac{G}{\sqrt{H} \times 13}\right)^{\frac{1}{2}}$$

Table 2 has been calculated by these rules; thus, for a 7-inch pipe discharging 450 gallons, the Table shows that the head necessary to generate the velocity at entry is 6 inches; this is irrespective of friction, which, in fact, for so short a tube as the rule supposes, would be practically nothing. This Table applies to all cases of pipes; for instance, Fig. 4 shows the inlet end of a main from a reservoir, which will require for the velocity at entry alone the amount of head shown by the Table. When, as is usually the case, the pipe is of considerable length, the head due to friction must also be allowed for.

(4.) "*Friction of Long Pipes.*"—With a long pipe there is not only the loss of head due to the velocity at entry, but also another loss due simply to the friction of the water against the sides of the pipe, so that in all cases the head consumed may be considered as composed of two portions:—one, the amount due to velocity of entry, irrespective of friction; and the other, the amount due to friction alone. Thus, in Fig. 8 the head h gives a certain velocity of discharge by the short pipe A; but to give the same velocity in the long main B C, the head H' is necessary, of which h' is consumed in generating the velocity at entry, being the same as for A, and the rest, or H, in the friction of the long pipe: the total head is, of course, the sum of the two.

(5.) The loss of head by friction may be calculated by the following rules:—

$$G = \left(\frac{(3d)^5 \times H}{L}\right)^{\frac{1}{2}}$$

$$H = \frac{G^2 \times L}{(3d)^5}$$

TABLE 2.—Of the ACTUAL DISCHARGE by SHORT TUBES of various DIAMETERS, with Square Edges and under Different Heads of Water Pressure, being $\frac{8}{10}$ths of the Theoretical Discharge.

Diam. in Inches.	HEAD OF WATER IN INCHES.																
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24
	DISCHARGE IN GALLONS PER MINUTE.																
1	3·76	5·28	6·48	7·52	8·4	9·2	9·9	10·6	11·3	11·8	13·0	14·1	15·0	15·9	16·9	17·6	18·4
2	15·01	21·12	25·9	30·1	33·6	36·8	39·7	42·6	45·1	47·4	51·4	56·3	60·2	63·7	67·2	70·4	[illegible]
3	33·8	47·5	58·3	67·7	75·6	82·4	89·6	96·0	101·6	104·4	116·9	126	[illegible]	[illegible]	151	[illegible]	[illegible]
4	60·2	84·8	104	120	130	147	158	170	180	189	207	[illegible]	241	[illegible]	[illegible]	[illegible]	[illegible]
5	93·6	132	162	188	210	230	218	266	282	[illegible]	321	[illegible]	[illegible]	[illegible]	420	[illegible]	[illegible]
6	135	190	233	270	302	331	357	382	406	426	466	[illegible]	512	573	605	[illegible]	[illegible]
7	191	218	318	368	411	450	486	522	553	580	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	241	338	414	481	538	589	631	681	722	[illegible]	[illegible]	901	[illegible]	1019	[illegible]	1126	1174
9	305	427	525	609	680	745	805	863	914	[illegible]	1049	1110	1218	[illegible]	[illegible]	[illegible]	[illegible]
10	376	528	648	752	810	920	992	1064	1129	[illegible]	[illegible]	1404	1504	[illegible]	[illegible]	[illegible]	[illegible]
12	541	762	934	1082	1210	1325	1128	1532	1624	1707	[illegible]	2027	2166	[illegible]	2419	[illegible]	[illegible]
14	736	903	1268	1474	1646	1803	1944	2085	2211	2321	2540	[illegible]	2947	[illegible]	[illegible]	[illegible]	[illegible]
15	846	1188	1458	1692	1890	2070	2232	2394	[illegible]	[illegible]	2916	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	962	1352	1659	1925	2150	2355	2539	2724	[illegible]	3031	3319	[illegible]	[illegible]	4073	4301	[illegible]	4710
18	1218	1710	2099	2136	2722	2981	3214	3447	3662	[illegible]	[illegible]	[illegible]	[illegible]	5154	[illegible]	[illegible]	[illegible]
20	1504	2112	2592	3008	3360	3680	3968	4256	4512	[illegible]	5184	[illegible]	6016	[illegible]	[illegible]	[illegible]	[illegible]
22	1820	2552	3136	3640	4065	4452	4801	5119	5159	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8131	8514	[illegible]
24	2163	3016	3737	4331	4838	[illegible]	5712	6128	[illegible]	[illegible]	[illegible]	8104	[illegible]	9164	[illegible]	10144	[illegible]
30	3384	4752	5832	6768	7560	8250	8928	9576	10152	10656	11661	12672	[illegible]	[illegible]	[illegible]	15840	[illegible]

$$d = \left(\frac{G^2 \times L}{H}\right)^{\frac{1}{5}} \div 3$$

$$L = \frac{(3d)^5 \times H}{G^2}$$

In these rules d = diameter of the pipe in inches.
L = length in yards.
H = head of water in feet.
G = gallons per minute.

These rules require the use of logarithms to work them easily: thus, to find the discharge by a 7-inch pipe 3797 yards long with 45 feet head, we have:—

$$\begin{array}{rl}
7 \times 3 = 21 = & 1\cdot322219 \\
 & \underline{5} \\
 & 6\cdot611095 \\
\times\, 45 = & \underline{1\cdot653213} \\
 & 8\cdot264308 \\
\div\, 3797 = & \underline{3\cdot579441} \\
 & 2)\overline{4\cdot684867} \\
 & \underline{2\cdot342433} = 220 \text{ gallons per minute.}
\end{array}$$

Again, to find the head necessary to discharge 320 gallons per minute by an 8-inch pipe 3157 yards long, we have:—

$$\begin{array}{rl}
320 = & 2\cdot505150 \\
 & \underline{2} \\
 & 5\cdot010300 \\
\times\, 3157 = & \underline{3\cdot536699} \\
 & 8\cdot518999 \\
8 \times 3 = 24 = 1\cdot380211 \times 5 = & \underline{6\cdot901055} \\
 & \underline{1\cdot617944} = 41\cdot46 \text{ feet head.}
\end{array}$$

And again, to find the diameter for 110 gallons per minute with 66 feet head, the length being 273 yards, we have:—

$$
\begin{array}{rr}
110 = & 2\ 041393 \\
 & 2 \\
\hline
 & 4\ 082786 \\
\times\ 273 = & 2\ 436163 \\
\hline
 & 6\ 518949 \\
\div\ 56 = & 1\ 748188 \\
\hline
 & 5)4\ 770761 \\
\hline
\end{array}
$$

$$954152 = 9, \text{ and } \frac{9}{3} = 3 \text{ inches diameter}$$

Table 3 has been calculated by these rules, and will greatly facilitate the calculation of pipe questions, it also has the great advantage of requiring only the simple rules of arithmetic

(6) 1st Having G, L, and d given, to find H In the Table opposite the given number of gallons, and under the given diameter, is found the head due to a length of one yard, and multiplying that number by the given length in yards, gives the required head of water in feet Thus, taking our former illustration in (5), the head to deliver 320 gallons per minute by an 8-inch pipe 3457 yards long—opposite 320 gallons in the Table, and under 8 inches diameter, is 01286 feet, and 01286 $\times$ 3457 = 44 46 feet, the head sought

(7) 2nd To find d, having H, L, and G given Divide the given head of water in feet by the given length in yards, and the nearest number thereto in the Table opposite the given number of gallons will be found under the required diameter Thus, to find, the diameter for 110 gallons per minute with 56 feet head, the length being 273 yards, we have $\frac{56}{273} =$ 205, looking for which in the Table opposite 110 gallons we find it under 3 inches, the diameter sought (see 5) Again, to find the diameter for 320 gallons, 20 feet head, and 1600 yards long, we have $\frac{20}{1600} =$ 0125, the nearest number to which, in the Table (·01286) is found under 8 inches, the diameter sought In most cases the tabular number will not be the exact number.

TABLE 3.—Of the HEAD of WATER CONSUMED by FRICTION with Pipes 1 yard long

Gallons per Minute.	Diameter of the Pipe in Inches: 1	1½	2	2½	3	3½	4
	Head of Water in Feet						
1	0041	00054	00012	000012	000016	0000078	[illegible]
2	0164	00216	00051	000168	000067	0000313	[illegible]
3	0370	00487	00115	000379	000152	0000705	[illegible]
4	0658	00867	00205	000674	000271	000125	[illegible]
5	1028	01354	00321	001053	000423	000195	[illegible]
6	1481	01950	00463	001517	000603	000282	[illegible]
7	2016	02655	00670	002064	000830	000383	[illegible]
8	2633	03468	00823	002696	001084	000501	[illegible]
9	3333	04389	01041	003413	001372	000634	[illegible]
10	411	0541	01286	00421	00169	000783	[illegible]
20	1 64	2167	0514	01685	00677	00313	[illegible]
30	3 70	4877	115	03792	0152	00707	[illegible]
40	6 58	8670	205	06742	0271	01253	[illegible]
50	10 28	1 35	321	1053	0423	01958	[illegible]
60	14 81	1 95	463	1517	0609	02820	[illegible]
70	20 16	2 65	630	2064	0830	03839	[illegible]
80	26 33	3 46	823	2696	1084	05014	[illegible]
90	33 33	4 38	1 011	3413	1372	06346	[illegible]

Gallons per Minute.	Diameter of the Pipe in Inches: 5	6	7	8	9	10	12
	Head of Water in Feet						
10	000131	000052	000024	000012	0000069	00000411	00000165
20	000526	000211	000097	000050	0000278	00001646	00000661
30	001185	000476	000290	000113	0000627	00003703	00001488
40	002003	000504	000372	000191	0001060	00006259	00002515
50	003292	001393	000612	000314	0001742	0001028	0000413
60	004741	001905	000881	000452	0002569	0001481	0000595
70	006153	002593	001200	000615	0003415	0002016	0000810
80	008428	003386	001567	000803	0004460	0002633	0001058
90	010667	004286	001983	001017	0005645	0003333	0001339

Note.—For intermediate numbers, see body of general Table 3 as explained in (10) page 16

Hydraulic Table 3—continued.

Gallons per Minute.	1	1½	2	2½	3	3½	4	5	6	7	8	9
	Head of Water in Feet											
100	41 1	5 4	1 28	·421	160	·078	·0101	·01317	·007292	·00214	·001276	[illegible]
110	49 7	6 5	1 55	·509	205	091	·0186	·01523	[illegible]	[illegible]	·001519	[illegible]
120	59 2	7 8	1 85	606	243	112	·0379	·018[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
130	69 5	9 1	2 17	712	286	132	·0679	·02225	[illegible]	·00113	·002122	·00117
140	80 6	10 6	2 52	825	332	153	·0789	·02541	·010772	·00140	[illegible]	[illegible]
150	92 5	12 1	2 89	·948	381	176	·0901	[illegible]	·011907	[illegible]	[illegible]	[illegible]
160	105 3	13 8	3 29	1 078	433	·200	1024	·03371	·012547	[illegible]	[illegible]	·00174
170	118 9	15 6	3 71	1 217	485	·226	1161	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
180	133 3	17 5	4 16	1 365	549	·253	1312	01277	·017146	[illegible]	[illegible]	[illegible]
190	148 5	19 5	4 64	1 521	611	·282	1450	01751	·019101	·00844	[illegible]	·00231
200	164 6	21 6	5 14	1 685	677	313	1607	·032[illegible]3	·021164	[illegible]	[illegible]	·00274
210	181 4	23 8	5 67	1 858	747	345	1772	·03807	[illegible]	·01030	[illegible]	[illegible]
220	199 1	26 2	6 22	2 039	819	379	1943	·03371	[illegible]	·01145	[illegible]	[illegible]
230	217 6	28 6	6 80	2 229	896	414	2126	[illegible]	[illegible]	·01293	[illegible]	[illegible]
240	237 0	31 2	7 40	2 427	·975	451	2314	[illegible]	[illegible]	·01110	[illegible]	·00101
250	257 1	33 8	8 03	2 633	1·058	489	·2511	·08231	[illegible]	·01520	·007450	·00135
260	278 1	36 6	8 69	2 818	1 145	529	·2716	[illegible]	·035773	·01655	[illegible]	·00171
270	299 9	39 5	9 37	3 071	1·231	571	·2929	[illegible]	·038374	·01745	[illegible]	[illegible]
280	322 6	42 4	10 08	3 303	1 328	614	3150	10323	[illegible]	[illegible]	[illegible]	·00310
290	316 0	45 5	10·81	3 544	1 424	659	3379	11073	·041504	·02050	[illegible]	·00340
300	370 3	48 7	11 59	3 792	1 524	·705	3617	11853	[illegible]	·02201	·011704	[illegible]
310	395 4	52 0	12 35	4 019	1 627	·752	3162	12655	[illegible]	·02353	·012070	[illegible]

HYDRAULIC TABLE 3—*continued*

Gallons per Minute.	1	1½	2	2½	3	3½	4	5	6	7	8	9
	Diameter of the Pipe in Inches											
	Head of Water in Feet											
320	421 3	55 5	13 16	4 315	1 734	802	4115	13186	054190	02507	012861	00713
330	448 1	59 0	14 00	4 589	1 814	853	4376	14342	057630	02669	013677	00759
340	475 6	62 6	14 87	4 871	1 958	905	4645	15224	061175	02831	014519	00805
350	501 0	66 3	15 75	5 162	2 075	959	4923	16133	064827	03000	015386	00853
360	533 3	70 2	16 66	5 461	2 196	1 015	5248	17068	068584	03173	016277	00903
370	563 3	74 1	17 60	5 769	2 336	1 072	5502	18029	072447	03352	017194	00954
380	594 2	78 2	18 57	6 085	2 446	1 131	5803	19017	076416	03536	018136	01006
390	625 8	82 4	19 56	6 409	2 576	1 191	6112	20031	080491	03724	019103	01060
400	658 4	86 7	20 57	6 742	2 710	1 253	6430	21072	0846[illegible]2	03918	020096	01115
410	691 7	91 0	21 61	7 083	2 847	1 317	6755	22138	088958	04116	021116	01171
420	725 8	95 5	22 68	7 433	2 988	1 382	7089	23231	093350	04320	022155	01229
430	760·8	100 1	23 8	7 79	3 13	1 448	743	2435	09784	04528	023223	01288
440	796 6	104 9	24 9	8 15	3 27	1 516	778	2549	10245	04741	024316	01349
450	833 2	109 7	26 0	8 53	3 43	1 586	813	2666	10716	04959	025434	01411
460	870 7	114 6	27 2	8 91	3 58	1 657	850	2786	11197	05182	026576	01474
470	909 0	119 7	28 4	9 30	3 74	1 730	887	2909	11690	05409	027745	01539
480	948 0	124 8	29 6	9 70	3 90	1 805	925	3034	12192	05642	028938	01605
490	988 0	130 1	30 8	10 11	4 06	1 881	964	3162	12706	05880	030156	01673
500	1028 7	135 4	32 1	10 53	4 23	1 958	1 004	3292	13230	06122	031400	01742
520	1112 7	146 5	34 7	11 39	4 58	2 118	1 086	3561	14309	06622	033962	01884
540	1200 0	158 0	37 5	12 28	4 93	2 284	1 171	3810	15431	07141	036624	02032
560	1290 4	169 9	40 3	13 21	5 31	2 157	1 260	4130	16595	07680	039388	02185

HYDRAULIC TABLE 3—*continued*

Gallons per Minute.	Diameter of the Pipe in Inches.											
	1	1½	2	2½	3	3½	4	5	6	7	8	9
	Head of Water in Feet											
580	1381 2	182 2	43 2	14 17	5 69	2 635	1 351	4430	17802	08238	012251	02344
600	1481 4	195 0	46 3	15 17	6 09	2 820	1 416	4741	19051	08816	015216	02[illegible]00
620	1581 8	208 3	49 4	16 19	6 51	3 011	1 514	5062	20312	09113	018280	02679
640	1685 5	222 0	52 6	17 26	6 93	3 209	1 616	5394	21676	10311	051145	02854
660	1792 5	236 0	56 0	18 35	7 37	3 412	1 750	5736	23051	10667	054711	03036
680	1902 7	250 5	59 4	19 48	7 83	3 622	1 858	6089	24470	11324	058077	03222
700	2016 3	265 5	63 0	20 64	8 30	3 839	1 969	6453	25930	12000	061514	03415
720	2133 2	280 9	66 6	21 84	8 78	4 061	2 099	6827	27433	12695	065111	03613
740	2253 3	296 7	70 4	23 07	9 44	4 290	2 200	7211	28979	13410	068778	03816
760	2376 8	313 0	74 2	24 34	9 78	4 525	2 321	7606	30566	14145	072516	04025
780	2503 5	329 6	78 2	25 63	10 30	4 766	2 445	8012	32196	14899	076115	04240
800	2633 6	346 8	82 3	26 96	10 84	5 014	2 572	8428	33869	15673	080384	04460
820	2766 9	364 3	86 4	28 33	11 39	5 268	2 702	8855	35583	16467	084464	04686
840	2903 5	382 3	90 7	29 73	11 95	5 528	2 835	9292	37340	17280	088623	04918
860	3043 4	400 7	95 5	31 16	12 52	5 794	2 972	9740	39139	18112	092893	05155
880	3186 6	419 6	99 5	32 63	13 11	6 067	3 112	1 0298	40981	18965	097264	05397
900	3333 1	438 9	104 1	34 13	13 72	6 346	3 255	1 0667	42865	19836	101736	05645
920	3482 9	458 6	108 8	35 66	14 38	6 631	3 401	1 1147	44791	20728	106307	05899
940	3636 0	478 8	113 6	37 23	14 96	6 923	3 551	1 1637	46760	21639	110980	06158
960	3792 4	499 4	118 5	38 83	15 61	7 220	3 703	1 2137	48771	22569	115752	06423
980	3952 0	520 4	123 5	40 47	16 26	7 524	3 859	1 2648	50824	23520	120626	06693
1000	4115 0	541 9	128 6	42 14	16 94	7 835	4 019	1 3170	52920	24490	125600	06970

HYDRAULIC TABLE 3—*continued.*

Gallons per Minute	Diameter of the Pipe in Inches. 10	12	14	15	16	18	20	21	24
	Head of Water in Feet								
100	000111	000165	0000765	0000541	0000392	0000217	0000128	0000100	00000516
110	000137	000200	0000925	0000655	0000474	0000263	0000155	0000121	00000625
120	000332	000238	0001101	0000780	0000565	0000313	0000185	0000145	00000744
130	000695	000273	0001293	0000915	0000663	0000368	0000217	0000170	00000873
140	000806	000321	0001499	0001062	0000769	0000426	0000252	0000197	00001012
150	000925	000372	0001721	0001219	0000883	0000490	0000289	0000226	00001162
160	001053	000423	0001958	0001387	0001004	0000557	0000329	0000257	00001323
170	001189	000477	0002211	0001566	0001134	0000629	0000371	0000291	00001493
180	001333	000535	0002479	0001755	0001270	0000705	0000416	0000326	00001674
190	001485	000597	0002762	0001956	0001416	0000786	0000464	0000363	00001865
200	001646	000661	0003060	0002167	0001569	0000871	0000514	0000403	00002067
210	001814	000729	0003374	0002389	0001730	0000960	0000567	0000444	00002279
220	001991	000800	0003703	0002622	0001899	0001054	0000622	0000487	00002501
230	002176	000874	0004047	0002866	0002076	0001152	0000680	0000533	00002733
240	002370	000952	0004407	0003121	0002260	0001254	0000740	0000580	00002977
250	002572	001033	0004782	0003387	0002452	0001361	0000803	0000629	00003231
260	002781	001117	0005172	0003662	0002653	0001472	0000869	0000681	00003493
270	00 000	001205	0005578	0003950	0002861	0001587	0000937	0000734	00003767
280	003226	001296	0005998	0001218	0003076	0001707	0001008	0000789	00001051
290	003460	001390	0006435	0004557	0003300	0001831	0001081	0000847	00004316
300	003703	001488	0006886	0001877	0003532	0001960	0001157	0000906	00004651
310	003954	001589	0007353	0005207	0003771	0002093	0001235	0000968	00004966

HYDRAULIC TABLE 3—*continued*

Gallons per Minute	Diameter of the Pipe in Inches. 10	12	14	15	16	18	20	21	24
	Head of Water in Feet								
320	001213	001693	0007832	0005519	0004018	0002230	0001316	0001032	00005292
330	001481	001800	0008332	0005901	0004273	·0002371	0001400	0001097	00005628
340	001757	001911	0008845	0006264	0004536	0002517	0001486	0001161	00005974
350	005011	002026	0009373	0006638	0004807	0002678	0001575	0001234	00006331
360	00 333	002142	0009916	0007023	0005082	0002822	0001666	0001305	00006697
370	005633	002261	0001017	0007418	0005372	0002981	0001760	0001379	00007075
380	005912	002388	0011048	0007625	0005667	0003145	0001856	0001454	00007462
390	006239	002515	0011638	0008242	0005969	0003312	0001956	0001532	00007860
400	006581	002616	0012212	0008670	0006279	0003481	0002057	0001612	00008269
410	006917	002780	0012862	0009109	0006597	0003661	0002170	0001693	00008687
420	007259	002917	0013497	0009559	0006923	0003811	0002268	0001777	00009116
430	00760	00305	001414	001002	000725	000402	000237	000186	0000955
440	00796	00320	001481	001049	000759	000421	000248	000195	0001000
450	00833	00334	001549	001097	000794	000441	000260	000204	0001046
460	00870	00349	001619	001146	000830	000460	000272	000213	0001093
470	00909	00365	001690	001197	000866	000481	000284	000222	0001141
480	00948	00381	001762	001248	000904	000501	000296	000232	0001190
490	00988	00397	001837	001301	000942	000522	000308	000241	0001245
500	01028	00413	001912	001354	000981	000544	000321	000251	0001292
520	01112	00447	002069	001461	001061	000588	000347	000272	0001397
540	01200	00482	002231	001580	001144	000635	000374	000293	0001507
560	01290	00518	002399	001699	001230	000683	000403	000315	0001620

HYDRAULIC TABLE 3—*continued*

Gallons per Minute.	Diameter of the Pipe in Inches.								
	10	12	14	15	16	18	20	21	24
	Head of Water in Feet								
580	01384	00536	002574	001823	001320	000732	000432	000338	0001738
600	01481	00575	002754	001950	001412	000784	000462	000362	0001860
620	01581	00635	002941	002083	001508	000837	000494	000387	0001986
640	01685	00677	003134	002219	001607	000892	000526	000412	0002116
660	01792	00720	003333	002360	001709	000948	000560	000438	0002251
680	01902	00764	003538	002505	001814	001007	000594	000465	0002389
700	02016	00810	003749	002655	001923	001071	000630	000493	0002532
720	02133	00856	003966	002809	002032	001129	000666	000523	0002679
740	02253	00905	004190	002967	002151	001192	000704	000551	0002830
760	02376	00955	004419	003130	002266	001258	000742	000581	0002985
780	02503	01006	004655	003297	002387	001325	000782	000613	0003144
800	02633	01058	004897	003468	002511	001393	000823	000644	0003307
820	02767	01112	005144	003643	002638	001464	000868	000677	0003475
840	02903	01166	005398	003823	002769	001536	000907	000710	0003616
860	03013	01223	005659	004008	002902	001610	000951	000745	0003822
880	03186	01280	005925	004196	003038	001686	000995	000780	0004002
900	03373	01339	006197	004389	003178	001764	001041	000816	0004186
920	03483	01399	006476	004586	003321	001843	001088	000852	0004374
940	03636	01461	006760	004788	003467	001924	001136	000890	0004566
960	03792	01524	007051	004994	003616	002007	001184	000928	0004763
980	03952	01588	007348	005204	003769	002091	001235	000967	0004982
1000	04115	01653	007651	005419	003924	002178	001286	001007	0005168

HYDRAULIC TABLE 3—*continued*

Gallons per Minute.	Diameter of the Pipe in Inches						
	5	6	7		9	10	12
	Head of Water in Feet						
2 000	5 2	2 11	97	50	27	164	066
3,000	11 8	4 76	2 20	1 13	62	370	118
4 000	21 0	8 46	3 91	2 00	1 11	659	264
5 000	32 9	13 23	6 12	3 11	1 74	1 02	413
6 000	47 4	19 05	8 81	4 52	2 50	1 48	595
7 000	64 5	25 93	12 00	6 15	3 41	2 01	910
8 000	81 2	33 86	15 67	8 03	4 46	2 63	1 05
9 000	106 6	42 86	19 83	10 17	5 64	3 33	1 33
10 000	131 7	52 92	24 49	12 56	6 97	4 11	1 65
20,000	526 8	211 68	97 96	50 24	27 88	16 46	6 61

Gallons per Minute.	Diameter of the Pipe in Inches.						
	14	15	16	18	20	21	24
	Head of Water in Feet						
2 000	0306	0216	0156	0087	0051	0040	
3 000	0688	0187	0353	0196	0115	0090	
4 000	122	0867	0627	0318	0205	0161	
5 000	191	135	0981	0544	0321	0251	
6 000	275	195	141	0784	0462	0362	
7 000	374	265	192	107	0630	0493	
8 000	489	346	251	139	0823	0644	
9 000	619	438	317	176	104	0810	
10 000	765	541	392	217	128	100	
20 000	3 06	2 16	1 56	871	514	403	
30 000	6 88	4 87	3 53	1 96	1 15	906	
40 000	12 24	8 67	6 27	3 18	2 05	1 61	
50 000	19 12	13 54	9 81	5 44	3 21	2 51	
60 000	27 54	19 50	14 12	7 84	4 62	3 62	
70 000	37 49	26 55	19 23	10 71	6 30	4 93	
80 000	48 97	34 68	25 11	13 93	8 23	6 44	
90 000	61 97	43 89	31 78	17 64	10 41	8 16	
100 000	76 51	54 19	39 24	21 78	12 86	10 07	

Note.—For intermediate numbers, see body of the general Table 3, as explained in (10) page 14.

desired, which will only show that the exact diameter is an odd size between the standard ones in the Table But by the former rule in (6), this can be easily checked, thus in our case the true head for an 8 inch pipe would be 01286 × 1600 = 20 57 feet instead of 20 feet, but, of course, in most cases 8 inches is near enough for practice

(8) 3rd To find G, having H, L, and *d* given Divide the given head of water in feet by the given length in yards, and the nearest number thereto in the Table, under the given diameter, will be found opposite the required number of gallons Thus, to find the discharge of a 7-inch pipe 3797 yards long with 45 feet head, see (5), we have $\frac{45}{3797}$ = 01185, and looking for this under 7 inches diameter, we find it opposite 220 gallons, the discharge sought Again, for the discharge of a 10 inch pipe 3000 yards long with 40 feet head, we have $\frac{40}{3000}$ = 01333, and the nearest number to that we find to be 01384 opposite 580 gallons, the discharge sought

(9) 4th To find L, having H, G, and *d* given Divide the given head by the head for one yard found in the Table under the given diameter, and opposite the given number of gallons, and the result is the required length Thus, to determine the length of 4 inch pipe to consume 12 feet head with 130 gallons per minute, we find under 4 inches and opposite 130 gallons 0679 the head for one yard, and hence $\frac{12}{0679}$ = 176 yards, the length sought

(10) To avoid a needless extension of the Table, we have given only the principal numbers from 1 to 90, and from 1000 to 100 000 gallons, leaving the intervening numbers to be supplied from the body of the general Table In order to do this, it should be observed that the head varies as the square of the discharge, so that, for instance, ten times any given discharge will require 100 times the head, &c., &c. Thus, with 100 gallons, the Table shows that a 5 inch pipe requires 01317 foot

head per yard, then with 1000 gallons the head would be $01317 \times 100 = 1\ 317$ foot, and with 10 gallons $\frac{01317}{100} =$ 0001317 foot The application of this principle to any case in practice is very simple say we require the head for 33 gallons with a $2\frac{1}{2}$-inch pipe 600 yards long Not finding 33 gallons in the Table, we take 330, the head for which is 4 589, therefore for 33 gallons it will be $\frac{4\ 589}{100} =$ 04589 This may be checked by the skeleton Table, which shows that 30 gallons require 03792 and 40 gallons 06742 foot, so that 04589 looks about right for 33 gallons Then the head required in our case is $04589 \times 600 = 27\ 534$ feet

Again say we required the head for 2800 gallons with a *15 inch pipe 500 yards long Here we must take the head* for 280 gallons from the Table, which is 0004248 for 2800 gallons, therefore, or 10 times the quantity, we should have $0004248 \times 100 = 04248$ foot Checking this by the skeleton Table we find 0487 foot for 3000 gallons, showing that 04248 foot for 2800 gallons is about right Hence the head sought is, in our case, $04248 \times 500 = 21\ 24$ feet

The same principle may be applied when the discharge is the unknown quantity, thus, to find the discharge of a $2\frac{1}{2}$ inch pipe, 700 yards long with 17 feet head, we have $\frac{17}{700} =$ 02428, which, by the skeleton Table, is somewhere between 20 and 30 gallons now, looking in the body of the Table between 200 and 300 gallons for the same figures (neglecting altogether for the moment the position of the decimal place) we find that the nearest to 2428 is 2427, which is opposite 240 gallons, 24 gallons is therefore the true discharge. Again, to find the discharge of a pipe $1\frac{1}{2}$ inch diameter, 200 yards long, with 4 5 feet head, we have $\frac{4\ 5}{200} =$ 0225, which, by Table, is between 6 and 7 gallons, now, looking between 600 and 700 gallons, we find the nearest to be 222 opposite 640 gallons, and as we know that

the true discharge is between 6 and 7 gallons, we infer that the exact quantity is 6·4 gallons, &c, &c

(11) The 3rd illustration in (8) for finding G may be extended so as to give a useful general view of the discharge of different sized pipes with the same length and head. Thus, we found the tabular number for 3000 yards long and 40 feet head to be $\frac{40}{3000}$ = ·01333, and looking for this successively undes different diameters we find that

A 6-inch	pipe	discharges	160	gallons	per minute
„ 7	„	„	235	„	„
„ 8	„	„	330	„	„
„ 9	„	„	440	„	„
„ 10	„	„	580	„	„
„ 12	„	„	900	„	„ &c

(12) "*Head for Velocity of Entry*"—To the head thus found by the preceding rules and Table, that due to velocity of entry has in all cases to be added, as explained in (4) When the pipe is of the common form, with square edges, as in Figs. 3 and 4, Table 2 gives the head for velocity direct For very long pipes this is so small in proportion to the head due to friction, that it may in such cases be neglected, and we have omitted it for that reason in the preceding illustrations, thus, we found in (5) and in (6) that with 320 gallons, by an 8 inch pipe 3457 yards long, the head due to friction alone was 44·46 feet By Table 2 it will be seen that the head for velocity at entry is rather less than 2 inches, so that in such a case it may be neglected But when a pipe is very short, the head due to velocity may be much greater than that due to friction, and the most serious errors may be made by neglecting it Say we had an 18-inch pipe, 20 yards long, discharging 3000 gallons By Table 3 the friction is ·0196 × 20 = ·392 foot, and the head due to velocity by Table 2 is 6 inches, or ·5 foot, being more than that due to friction, so that the total head is ·392 + ·5 = ·892 foot

(13) When, with a very short pipe, the head is given and the discharge has to be calculated, the case does not admit of a

simple direct solution, because we cannot tell beforehand in what proportions the total head at disposal has to be divided between overcoming friction and generating velocity. We must for such cases, apply a useful general law (27), which may be stated as follows :—" *The discharge by any pipe or series of pipes, is proportional to the square root of the head*," and conversely, " *The head is proportional to the square of the discharge*," and these laws are true in pipes with bends jets, contractions, &c. Thus, say we require the discharge of a 12 inch pipe 5 yards long with 10 feet head. Assume a discharge, it is unimportant whether the assumed discharge is near the true quantity or not, or whether it is too much or too little. Say, in our case, we take it at 1000 gallons per minute, then by Table 3 the head for friction is .01653 × 5 = .08265 foot, and the head for velocity is, by Table 2, about 4 inches, or .333 foot, making a total of .08265 + .333 = .41565 foot, instead of 10 feet, the head at disposal. Then applying the law just given, we have $\frac{1000 \times \sqrt{10}}{\sqrt{.41565}} = \frac{1000 \times 3.162}{.6447} = 4905$ gallons. Now, if in this case the head due to velocity had been neglected, the discharge by Table 3 would be $\frac{10}{5} = 2.0 = 11{,}000$ gallons, which is more than double the true discharge. The Table 2 gives the greatest possible facility for making the calculations of head due to velocity, which should never be overlooked in cases where the pipe is short.

(14.) "*Loss of Head by Bends*.—There is another source of loss of head in pipes—namely, change of direction or bends. The best formula for calculating this loss is that of Weisbach, which may be modified into the following :—

$$H = \left\{ .131 + (1.847 \times \left(\frac{r}{R}\right)^{\frac{7}{2}} \right\} \times \frac{V^2 \times \phi}{960},$$

$$\text{and } V^2 = \frac{960 \times H}{\phi \times \left\{ .131 + (1.847 \times \left(\frac{r}{R}\right)^{\frac{7}{2}} \right\}}.$$

In which H = the head due to change of direction, in inches
r = radius of the bore of the pipe, in inches
R = radius of the centre line of the bend, in inches
ϕ = angle of bend, in degrees.
V = velocity of discharge, in feet per second

Thus, say we require the loss of head by a bend of 9 inches radius in a 6 inch pipe, discharging 800 gallons per minute, with an angle of 55° A 6 inch pipe containing roughly $\frac{6^2}{30} = 1\ 2$ gallon per foot run the velocity of discharge will be $\frac{800}{1\ 2 \times 60} = 11\ 1$ feet per second To find $\left(\frac{r}{R}\right)^{\frac{7}{2}}$, or in our case $\left(\frac{3}{9}\right)^{\frac{7}{2}}$, we have $\frac{3}{9} = \ 3333$

Then the log of $\ 3333 = \bar{1}\ 522835$

$$\begin{array}{r} \bar{1}\ 522835 \\ 7 \\ \hline 2)\bar{4}\ 659845 \\ \hline \bar{2}\ 329922 \end{array} = \ 02137 = \left(\frac{3}{9}\right)^{\frac{7}{2}}$$

Then $\left\{\ 131 + (1\ 847 \times \ 02137\right\} \times \frac{11\ 1^2 \times 55}{960} = 1\ 2$ inch the head required

Table 4 has been calculated by the second formula. The first part is adapted to bends of the radius usually met with in practice this may vary slightly with different makers but not so much as to affect the result seriously Fig 6 gives the proportions of the 8 inch bend as an illustration The second part of the Table gives the loss by *quick* bends of the proportions given by Fig 7, which are sometimes necessary in special cases they are commonly named elbows

Table 4 requires but little explanation, it shows for instance that an ordinary 8 inch bend with 18 inches radius consumes 3 inches head when passing 1970 gallons per minute, but a quick 8 inch bend with 6 inches radius consumes 12 inches

TABLE 4.—TABLE for BENDS in WATER PIPES, showing the LOSS of HEAD DUE to CHANGE of DIRECTION by ONE BEND of 90°

Diameter of the Pipe in Inches.	Radius of Centre line of Bend in Inches.	Head of Water in Inches lost by One Bend of 90°														
		⅛	¼	½	¾	1	1½	2	3	4	5	6	9	12	18	24
		Gallons Discharged per Minute.														
2	12	25	36	51	63	73	81	103	126	146	163	173	219	252	309	358
3	12	58	83	117	144	166	203	235	288	312	371	407	498	576	705	811
4	12	102	145	205	252	291	356	411	504	582	650	713	873	1003	1233	1126
5	18	162	229	324	396	458	561	618	793	916	1024	1122	1374	1586	1944	2214
6	18	232	328	461	568	656	803	928	1130	1312	1167	1607	1968	2272	2784	3124
7	18	309	437	618	757	874	1070	1236	1514	1718	1934	2141	2622	2929	3709	4232
8	18	402	563	801	985	1137	1393	1608	1970	2274	2542	2786	3111	3740	4821	5772
9	18	501	709	1002	1228	1418	1737	2005	2456	2836	3170	3174	4234	4912	6015	6948
10	18	606	857	1212	1484	1714	2100	2424	2968	3428	3832	4179	5142	5876	7272	8794
12	21	866	1225	1733	2122	2451	3003	3166	4245	4902	5180	6003	7353	8190	10789	12010
15	24	1317	1861	2635	3229	3728	4567	5271	6457	7456	8376	9131	11184	12911	15813	18268
18	27	1857	2626	3714	4549	5253	6135	7428	9098	10506	11745	12870	15739	18196	22284	25719
21	30	2167	3490	4935	6044	6980	8550	9870	12089	13960	15607	17100	20940	24178	29610	34900
24	33	3165	4477	6330	7754	8954	10968	12661	15508	17908	20021	21937	26862	31016	37983	43870

TABLE FOR QUICK BENDS.

Diameter of the Pipe in Inches.	Radius of Centre line of Bend in Inches.	⅛	¼	½	¾	1	1½	2	3	4	5	6	9	12	18	24
2	3	23	32	46	56	65	79	92	112	130	145	159	195	214	276	319
3	3½	44	63	89	109	126	154	178	218	252	282	309	378	476	534	618
4	4	69	98	139	170	197	241	278	311	394	410	480	541	682	831	968
5	4½	96	136	172	236	272	333	385	472	514	609	646	816	914	1175	1332
6	5	128	181	256	314	362	443	512	629	724	809	886	1056	1278	1576	1774
7	5½	161	229	322	396	458	561	615	793	917	1024	1122	1374	1586	1935	2214
8	6	199	281	398	487	563	689	796	975	1126	1259	1379	1689	1930	2588	2738

head when passing nearly the same quantity, or 1950 gallons, and these, it should be observed, are the heads due simply to *change of direction*, and do not include the head due to velocity or to friction Thus, for instance, if the quick 8-inch bend had a length of one yard, the head for friction by Table 3 (say for 2000 gallons) would be 5 foot, and the head for velocity at entry by the rule in (3), namely $\left(\frac{G}{d^2 \times 13}\right)^2 = H$ is $\left(\frac{1950}{8^2 \times 13}\right)^2 = 5\ 48$ feet Thus we have a total for such a bend of

1 0 feet	for change of direction,
0 5 „	for friction,
5 48 „	for velocity at entry,
6 98 „	total

Again, in a 6-inch pipe carrying 800 gallons, the Table shows that each common bend causes a loss of $1\frac{1}{2}$ inches head, and each quick bend a loss of 5 inches, &c The Table is arranged for bends of 90°, or quarter bends, as they are technically named, but it is applicable to any other angle, for the loss of head is simply proportional to the angle, the radius being the same, thus, a half-quarter bend of 45°, or one-eighth part of a circle, consumes half the head of a bend of 90°, and a bend of 180°, or half a circle, takes double, &c, &c

(15) "*Discharge of Compound Water mains*"—When a long main is composed of pipes of different sizes, as is very frequently the case, the head for each must be separately calculated, and the sum total taken Thus, if we required 300 gallons per minute through a main 1200 yards long, composed of 800 yards of 7 inch, 300 yards of 6 inch, and 100 yards of 5 inch pipe, the head would be—

			By Table 3.		
300 gallons	7-inch	=	022 × 800	= 17 6	feet head
„	„ 6 „	=	0176 × 300	= 14 28	„
„	„ 5 „	=	1185 × 100	= 11 85	„
				43 73	total

If there were bends in the pipes we must add the head for

them from Table 4, but it will be found, as in the case of head for velocity, see (12), that with long mains the effect of bends is very small. Say we had

4 common	bends in the	7-inch,	each	$\frac{1}{8}$-inch head	=	$\frac{1}{2}$	inch
3 quick	„ „	7 „	„	$\frac{1}{2}$	„ =	$1\frac{1}{2}$	„
2 common	„ „	6 „	„	$\frac{1}{4}$	„ =	$\frac{1}{2}$	„
2 quick	„ „	6 „	„	$\frac{3}{4}$	„ =	$1\frac{1}{2}$	„
4 common	„ ,	5 „	„	$\frac{1}{2}$	„ =	2	„
3 quick	„ „	5 „	„	$1\frac{1}{2}$	„ =	$4\frac{1}{2}$	„
					Total	$10\frac{1}{2}$	inches

Thus, even for such a large number of bends, the loss of head is only $10\frac{1}{2}$ inches, or ·875 of a foot, so that the total loss is 43·73 + ·875 = 44·605 feet.

(16.) When, with such a series of pipes the head is given, and the discharge has to be determined, the case does not admit of a direct solution, because we cannot tell beforehand in what proportions the given head must be divided among the different pipes. We must in that case follow the course explained in (13) thus, say we required the discharge with 30 feet head by a main 2000 yards long, composed of 1200 yards of 8-inch pipe with four common bends in it, 700 yards of 6-inch pipe and three bends, and 100 yards of 5-inch pipe, with two common and two quick bends. The first thing to be done is to assume a discharge, and calculate the head for that, as was done in the last example, it is unimportant whether the assumed discharge is near the true quantity or not. Say in our case we take it at 400 gallons. Then

		By Table 3.		Length.		Feet.	
400 gallons 8-inch pipe	=	·02	×	1200	=	24·0	head
„ 6 „	=	·085	×	700	=	59·5	„
„ 5 „	=	·21	×	100	=	21·0	„
			Carried forward			104·5	

			Brought forward .		*101 5 feet*
		Inch	Inch	Inch	
1 common bends	in	8 each	$\frac{1}{8} \times 4 =$	$\frac{1}{2}$ head	
3 "	"	6 "	$\frac{1}{2} \times 3 =$	$1\frac{1}{2}$ "	
2 "	"	5 "	$\frac{3}{4} \times 2 =$	$1\frac{1}{2}$ "	
2 quick	"	5 "	$3 \times 2 =$	6 "	
				$9\frac{1}{2} =$	·8 foot
				Total	105 3 feet

Thus we find that for 400 gallons we require 105 3 feet head instead of 30 feet, the head given, then by the rule in (13) we have $\frac{\sqrt{30} \times 100}{\sqrt{105\ 3}}$ or $\frac{5\ 447 \times 400}{10\ 26} = 213$ gallons, the real discharge sought Further illustrations will be found in Chapter II

(17) "*Effect of Contour of Section*"—The contour of the section of the line of pipes is a matter of some importance The best condition, *when the pipe is of uniform diameter from end to end*, is, of course, a uniform slope throughout This, however, can rarely be obtained, the pipe having to follow the contour of the ground, as in Fig 9. If a number of open topped pipes were inserted anywhere along the main, as at A, B, C, D, &c , the water would rise in them to the level of the oblique line J K, which in the case of a pipe of the same bore from end to end, would be a straight line as shown , this line is termed the *hydraulic mean gradient* Now, the vertical distance from any point in that line (say the top of E) to the level line K M, will give the head for friction between E and K, and the vertical distance from the same point to the level line J L will give the friction between E and J we have here supposed, of course, that the figure is correctly drawn to scale

(18) When, as in Fig 11, the pipes are of different diameters, then each would have its own gradient, showing at every point the loss of head due to that particular pipe as in the figure No loss of effect will arise from the pipe following the section of the ground, *so long as the contour of the pipe does not anywhere along the line rise above the hydraulic mean gradient* Thus, in

Fig 9, where the ground is much broken, but does not anywhere rise above the gradient, the discharge will be the same as by a pipe with a uniform slope.

(19) But if, as in Fig 10, a hill, as at B, rises higher than the gradient, then the pipe from C to D will be in a state of partial vacuum, air will be given out by the water, and will accumulate at the summit, and being driven forward by the water from C to B, will remain permanently in the pipe from B to G, occupying the upper part of the pipe while the water trickles down the lower part as in a trough or open channel, and the vertical head from B to G is lost, the hydraulic gradient being now from A to B from B to G, and from G to F, this last being parallel to that from A to B, or at the same angle with the horizon The discharge at F will therefore be, not the amount due to the head E, F on the length A, F, but that due to the head E, B on the length A, B

(20) In this case the size of the pipe should not be uniform from end to end from A to B it should be of large diameter, so as to deliver at B the required quantity with the head E, B, and the pipe from B to F may be of smaller diameter, so as to deliver the same quantity at F with the head H, F Say we take a case with the length A, F = 5000 yards and head E, F = 90 feet, and that the length A B = 2400 yards, and the head E, B = 10 feet, and that 500 gallons were required at F. With uniform slope we should have $\frac{90}{5000} = 018$, which, by Table 3, is a 9-inch pipe, or rather less for a 9-inch pipe would deliver 500 gallons with $01742 \times 5000 = 87\ 1$ feet But for the delivery at B with 10 feet head, and a 9 inch pipe, we have $\frac{10}{2400} = 004167$, which by Table = 245 gallons only, instead of 500, and, of course, this is all we should get at F with such an arrangement, for whatever the size of the rest of the pipe from B to F might be, it could not deliver more than it received by the pipe A, B

The pipe from A to B should be $\frac{10}{2400} = 004167$, by Table 3

= a 12-inch pipe, and the pipe from B to F may be $\frac{80}{2600}$ = ·03077 = an 8-inch pipe by Table We may check these results thus —

		By Table 3.		Length		Head.	
12-inch pipe,	500 gallons =	00413	×	2400 =		9 912	feet
8 ,,	500 ,, =	0314	×	2600 =		81 64	,,
					Total	91 552	

Thus we find the exact head to be a little more than the head at disposal, but in most cases the agreement is near enough for practice

(21.) When a long main is composed of different sizes of pipes and passes over uneven ground the best course is to draw the gradients on the section of the pipes so as to see at a glance that none of the hill-tops rise above them Fig 11 is a case in which, with a fall of 232 feet, we have a 10 inch main 1000 yards long, an 8-inch main 3000 yards long, and a 6-inch main 2000 yards long To divide the given fall in the proper proportion between the different pipes and so find the gradients, let us assume that 100 gallons are delivered, then

		By Table 3.		Length	A	
100 gallons	10-inch =	000411	×	4000 =	1 644	feet head
,,	8 ,, =	001256	×	3000 =	3 768	,,
,,	6 ,, =	005292	×	2000 =	10 584	,,
					15 996	total head

Now, whatever the real head may be, it would have to be divided among the several pipes in the same proportions as for 100 gallons in Col A, and as the head in our case is $\frac{232}{15\ 996}$ = 14 504 times the total head for 100 gallons, it follows that the real head for each pipe will be 14 504 times the head for the same pipe in Col A, thus the true head

E, B	for the 10 inch pipe will be	1 644 × 14 504 =	23 84	feet
F, C	,, 8 ,, ,,	3 768 × 14 504 =	54 65	,,
G, D	,, 6 ,, ,,	10 584 × 14 504 =	153 51	,,
			232 00	

We can now draw the gradients on the section as in Fig 11, and then if the contour of the ground is below them throughout, all is well * The discharge at D may be calculated from any one of the pipes, say we take the 8-inch, then $\frac{54\ 65}{3000} = 01822 =$ about 380 gallons by Table 3

(22) "*Special Cases*"—There are many cases for the solution of which no general rules can be given—they require reasoning, with the assistance of rules The following cases may be useful —Say that with pipes, arranged as in Fig 12, we require 50 gallons at B, and 100 gallons at A, and have to determine the sizes of the mains If we assume 3 inches for E, the head for that size would be $0423 \times 160 = 6\ 77$ feet above the level at B, and as that point is 8 feet (or $18 - 10$) above the level at C, we have at this last point the head of $6\ 77 + 8 = 14{\cdot}77$ feet to deliver 50 gallons at B Now, as A is $25 - 18 = 7$ feet below C, the head on A will be $14\ 77 + 7 = 21\ 77$ feet, and to find the size of pipe with that head for 100 gallons, we have $\frac{21\ 77}{250} = 0871 =$ a 3½-inch pipe by Table 3 We have now only to fix the size of the pipe D to carry $50 + 100 = 150$ gallons we find the head at C necessary for the pipes E and F to be 14 77 feet, leaving therefore only $18 - 14\ 77 = 3\ 23$ feet for the friction of D and from this we find $\frac{3\ 23}{300} = 01077 =$ a 6-inch pipe by Table 3

(23) Take another case shown by Fig 13 and say that we require the head at D to deliver 600 gallons at E by the single and double line of pipes, also to find what proportion of the 600 gallons passes by the two branches A, C B and A, B Let us assume that the pipe A, C, B carries 1000 gallons, then the head at A for that quantity will be —

1000 gallons 12-inch pipe = 010[illegible] × 1100 = 18 18 feet head
" 9 " = 00[illegible]7 × [illegible] = [illegible] "
[illegible] "

* Th[illegible] [illegible]

And with that head at A, the pipe A, B would at the same time deliver $\frac{73 \cdot 94}{950} = \cdot 0778 = 790$ gallons by Table 3; so that the two sets of pipes deliver at B 1790 gallons with a head of 73·94 feet at A, and therefore (13) to deliver the 600 gallons required would take $\frac{73 \cdot 94 \times 600^2}{1790^2} = 8 \cdot 3$ feet. Then, the 12-inch pipe from D to A would require for 600 gallons $\cdot 00595 \times 1100 = 6 \cdot 545$ feet head, and the 9-inch pipe from B to E, $\cdot 02509 \times 400 = 10 \cdot 036$ feet; thus the total head at D will be $6 \cdot 545 + 8 \cdot 3 + 10 \cdot 036 = 24 \cdot 881$ feet. The pipe A, C, B will carry $\frac{600 \times 1000}{1790} = 336$ gallons, therefore the pipe A, B must take the rest, or 264 gallons.

(24.) If the head had been given, and the discharge due thereto had to be determined, we must have calculated the head for an assumed discharge, and then applied the rule in (13) to find the real discharge with the true head. Thus, say that with the same arrangement of pipes, we require the discharge at E with 45 feet head at D. If we assume 600 gallons, we should find 24·881 feet head as in (23); then $\frac{600 \times \sqrt{45}}{\sqrt{24 \cdot 881}}$ or $\frac{600 \times 6 \cdot 708}{4 \cdot 988} = 807$ gallons, the discharge at E with 45 feet head at D, &c.

(25.) *"Delivery and Suction-pipes to Pumps."*—In calculating the sizes of pipes to pumps, it should be remembered that the action of a pump is intermittent, especially where there is no air-vessel to equalize the velocity of supply and discharge. Say we have a single-acting pump 2 feet diameter and 2 feet stroke, worked by a crank, &c., making 16 revolutions per minute. The area of the pump being 3·1116 feet, we should have $3 \cdot 1116 \times 2 \times 16 = 100$ gallons discharged per minute; but while the bucket is descending the delivery is *nothing*, and it rises to a maximum when the bucket is at the centre of its up-stroke, where

it has the velocity of the crank pin, thus in our case the crank-path being 2 feet diameter, or 6 28 feet circumference, the maximum discharge at that moment is $6\ 28 \times 16 \times 3\ 1416 =$ 314 gallons, and the pipes must be calculated for that quantity instead of 100 gallons, the mean discharge In most cases, an air vessel is used, which more or less effectively regulates and equalizes the velocity of discharge, where the suction-pipe is a long one, an air-vessel should be provided for that also Table 5 gives the variation in velocity in different kinds of pumps without air vessels.

TABLE 5 —Of the VELOCITY of DISCHARGE by PUMPS WITHOUT AIR VESSELS

	Velocity of Discharge.			Variation per cent.
	Max.	Mean.	Min.	
One single-acting pump, worked by a crank	314 16	100	000	314 16
Two ditto, worked by cranks at right angles	222 00	100	000	222 00
One double-acting pump	157 08	100	000	157 08
Three-throw single-acting	104 76	100	90 69	14 07
Four single-acting or two double-acting	111 00	100	78 79	32 21

This Table shows that the common 3 throw pump has a more uniform discharge than any other, the maximum velocity being under 5 per cent in excess of the mean, an air-vessel is hardly necessary for such a case, in fact large pumps throwing 600 gallons per minute have been worked for many years successfully without any air-vessel

(26) "*Service-pipes in Towns*"—The sizes of street service-pipes for town supplies cannot be calculated by the ordinary rules we may pursue another method. Certain sizes of lead services varying with the sizes of the houses supplied have been found necessary by experience. For ordinary cases with intermittent supply we may admit that ½-inch pipe will suffice for a house with 6 or 7 rooms, ⅝ inch for 10 rooms, ¾-inch for 16 rooms, and 1-inch for say 20 rooms. The discharging power of long

pipes varies, as the 2 5 power of the diameter (28), thus $4^{2\ 5} = 32$, and we shall therefore require 32 1-inch pipes to deliver with the same head and length the same quantity of water as a 4-inch pipe, and we may admit that a 4-inch main would supply 32 1-inch lead services, &c Table 6 is calculated on these principles

TABLE 6 —SERVICE MAINS for WATER SUPPLY in TOWNS

Diameter of Branch Mains.	Diameter of Lead Services			
	½	⅝	¾	1
	Number of Houses supplied			
1½	15	9	6	3
2	32	18	12	6
2½	56	32	20	10
3	88	50	32	15
3½		74	47	23
4		104	66	32

"*General Laws for Pipes*"—The following general statement of the laws governing pipe questions may be useful some of these laws apply strictly only to long mains in which the head due to velocity may be neglected

(27) When d and L are constant, the discharge, or G, varies directly as the square root of the head, so that for heads in the ratio 1, 2, 3, the discharge would be in the ratio $\sqrt{1}$, $\sqrt{2}$, and $\sqrt{3}$, or 1, 1 414, and 1 732

Conversely,—the head is directly as the square of the discharge, so that for discharges in the ratio 1, 2, 3, we require heads in the ratio 1^2, 2^2 3^2, or 1, 4, 9, &c

(28) When H and L are constant, the discharge is directly as the 2 5 power of the diameter, thus with diameters in the *ratio 1, 2, 3, the discharge will be in the ratio* $1^{2\ 5}$, $2^{2\ 5}$, and $3^{2\ 5}$, or 1, 5 6, and 15 6

Conversely,—the diameter will vary directly as the 2 5 root of the discharge, thus for discharges in the ratio 1, 2, 3, the

diameter will vary in the ratio $\sqrt[5]{1}$, $\sqrt[5]{2}$, and $\sqrt[5]{3}$, or 1, 1 32, and 1·55, &c

(29) When G and L are constant, the head will be *inversely* as the 5th power of the diameter, so that for diameters in the ratio 1, 2, 4, the heads will be in the ratio 1^5, 2^5, and 1^5, or 1024, 32, and 1

Conversely,—the diameter will be inversely as the 5th root of the head, thus for heads in the ratio 1, 2, 4, the diameters would be in the ratio $\sqrt[5]{4}$, $\sqrt[5]{2}$, and $\sqrt[5]{1}$, or 1 32, 1 15, and 1·0, &c

(30) When H and d are constant, the discharge will be inversely as the square root of the length, thus for lengths in the ratio 1, 2, 4, the discharge would be in the ratio $\sqrt{4}$, $\sqrt{2}$, and $\sqrt{1}$, or 2 0, 1 414, and 1 0, &c

Conversely,—the length varies inversely as the square of the discharge, thus for discharges in the ratio 1, 2, 4, the lengths would be in the ratio 4^2, 2^2, and 1^2, or 16, 4, and 1, &c.

(31) When G and d are constant, the head is directly and simply as the length, thus for lengths in the ratio 1, 2, 3, the heads would also be in the ratio 1, 2, 3, &c

(32) "*Head for very Low Velocities*"—Table 3 gives the greatest possible facility for the calculation of pipe questions, as may be seen by the examples we have given, and for all ordinary cases the results are correct, but for very small velocities with low heads say under one foot, &c., experiment has shown that the discharges are less than that Table would give and for such cases Prony's more difficult and laborious rule seems to give the most correct results The following rule is based on that of Prony —

Let d = diameter of the pipe in inches
H = head of water in inches
L = length of pipe in feet.
G = gallons per minute

Then

$$\left(\left(16\ 353 \times \frac{H \times d}{L} + \ 00665\right)^{\frac{1}{2}} - \ 0816\right) \times d^2 \times 2\ 01 = G$$

Thus, say we required the discharge by a 12-inch pipe 3000 feet long with 36 inches head then

$$\left(\left(16\ 353 \times \frac{36 \times 12}{3000} + \ 00665\right)^{\frac{1}{2}} - \cdot 0816\right) \times 144 \times 2\ 04 -$$

427 4 gallons

We may compare this result with that by Table 3, or rather by the rule $\left(\frac{(3\,d)^5 \times \mathrm{H}}{\mathrm{L}}\right)^{\frac{1}{2}} = \mathrm{G}$, given in (5), by which the discharge comes out 426 gallons, or practically the same as by Prony's rule With a very small head, however, the two rules do not agree, thus, with only one inch head, this same pipe gives 54·87 gallons by Prony's rule, whereas the other rule gives 70 98 gallons, or 29 per cent more With a large head, *on the contrary, Prony's rule gives a rather larger discharge* than the other The general comparison of the two rules may be shown *by the case of a 10-inch pipe, 1000 yards long, the* calculated discharge of which, with different heads, is given by the following Table —

	Head of Water					
	in. 1	ins 4	ft. ins. 1 4	ft. ins. 5 4	ft. ins 21 4	ft. ins. 85 4
	Discharge in Gallons per Minut.					
By the Rule in (5)	*45*	*90*	*180*	*360*	*720*	*1110*
By Prony's Rule	33 8	80 05	174 6	361 7	715	1'07
Difference per cent.	+33 1	+11 8	+3 1	−1 2	−3 41	−4 15

(33) When the head is the unknown quantity, and the rest of the particulars are given, the rule becomes —

$$\frac{\left(\left(\frac{\mathrm{G}}{2\ 01 \times d^2} + \ 0816\right)^2 - \cdot 00665\right) \times \frac{\mathrm{L}}{d}}{16\ 353} = \mathrm{H}$$

Let us take an extreme case, in order to illustrate more fully the special adaptation of Prony's formula to very low velocities

Say we require the head for a 10 inch pipe 4000 feet long, discharging only 20 gallons per minute then

$$\frac{\left(\frac{20}{2\ 04 \times 100} + \ 0816\right)^2 - 00665\right) \times \frac{4000}{10}}{16\ 353} = \ 626 \text{ inch head}$$

Now, by Table 3, the head comes out 00001646 × 1333 = 02194 foot, or 263 inch only, so that in this very extreme case Prony's rule gives $\frac{626}{263} = 2\ 38$ times the head by the rule in (5) or Table 3

(34) Table 29 has been calculated by the following modification of Prony's rule —

$$\frac{(V + \ 0816)^2 - \ 00665}{196\ 24} = \frac{H \times d}{L},$$

In which d = diameter of pipe in inches
V = velocity of discharge in feet per second.
H = head of water in inches
L = length of pipe in inches

Table 29 has been calculated for small velocities only, because Table 3 gives results sufficiently correct for practical purposes, with higher velocities and is more facile in application We have added opposite each velocity in Table 29 the corresponding discharge of pipes from 1 inch to 24 inches diameter, in order to abridge the labour as much as possible For the use of this Table we have the following rules —

(35) 1st To find the discharge, having H, L, and d given. Multiply the given head in inches by the diameter in inches, and divide by the length in inches, and find the nearest number thereto in Col 1 Then opposite that number, and under the given diameter will be found the discharge in gallons per minute Say, we take the case in (32) to find the discharge of a 12 inch pipe 3000 feet or 36,000 inches long with 36 inches head. Then $\frac{H \times d}{L}$ or $\frac{36 \times 12}{36000} =$ 012, the nearest number to which in

Col 1 is ·01192, opposite to which, and under 12 inches diameter, is 427 gallons, the discharge sought

2nd To find the head, having G, L, and d given In Table 29, under the given diameter, find the nearest number of gallons, and take from Col 1 the number opposite to it, which number, multiplied by the length in inches, and divided by the diameter in inches, will give the required head in inches Thus, taking the extreme case in (33) to find the head for a 10 inch pipe 4000 feet long, with 20 gallons per minute —The nearest discharge under 10 inches diameter is 20 45 gallons, opposite which in Col 1 is 0001311, and from this we obtain $\frac{0001311 \times 48000}{10} =$ 643 inch head the exact head for 20 gallons we calculated in (33) to be 626 inch

It should be observed that Prony's formula does not include the head due to velocity of entry (12), which for short pipes becomes important It has been omitted in the preceding illustrations because with such long pipes as were given in our cases it is too small to affect the result sensibly for instance, in the last case, the head for velocity with 20 gallons per minute and a 10-inch pipe by the rule in (3) is $\left(\frac{20}{100 \times 13}\right)^2 = ·000237$ foot, or $\frac{1}{352}$nd of an inch only

(36) "*Square and Rectangular Pipes*"—The case of square or rectangular pipes may be assimilated to that of round ones, and the head or discharge may then be calculated by the same rules and Tables that we have given for the latter The *velocity* of discharge, whatever may be the form of the pipe or channel, is proportional to the hydraulic radius (57) or the sectional area, divided by the circumference or perimeter in round pipes this is always equal to one-fourth of the diameter

Say we have a rectangular channel 3 ft × 1 5 foot, Fig 39, the area is 4 5 feet, the perimeter 9 feet, and the hydraulic radius $\frac{4\ 5}{9} =$ 5 foot, which is the same as that of a round pipe 5 × 4 = 2 feet diameter Then to find the head for friction

with such a channel, say 100 yards long, discharging 270 cubic feet per minute, we have a velocity of $\frac{270}{4\ 5} = 60$ feet per minute, or 1 foot per second, which by Table 29 is equal to 1178 gallons per minute with a 24-inch pipe, and by Col 1 of the same Table $\frac{H \times d}{L} = 005928$, therefore $H = \frac{005928 \times L}{d}$, or in our case $\frac{\cdot 005928 \times (100 \times 36)}{24} = 889$ inch, the head required. We might have obtained the head approximately by Table 3, say for 1200 gallons $= 000744 \times (100 \times 12) = 8928$ inch

We might also have calculated the head more directly by Table 30 —Opposite 5 the given hydraulic radius, the nearest velocity to that given, or 60 feet per minute, is 61 feet, which is under 15 inches *fall per mile*, or 00852 inch per yard, hence for 100 yards the head is $00852 \times 100 = 852$ inch

The head for velocity at entry must be added to that for friction, and may be found by Table 15 thus, with a square edged inlet, the head for a velocity of 1 foot per second is given by Col C at $\frac{1}{4}$th of an inch, the total head is therefore $889 + \cdot 25 = 1\ 139$ inch

By the application of the same principles, the head, or discharge of a channel of any sectional form whatever may be determined.

(37) "*Effect of Corrosion or Rust in Pipes*"—The rules and Tables for calculating the discharge of pipes are adapted only to clean and even surfaces, such as are commonly met with in new cast-iron pipes. But some soft waters contain a great deal of oxygen, which rapidly decomposes iron, forming rust, which is deposited, not in an even layer, but in nodules or carbuncles

These retard the flow, not so much by the reduction of diameter as by the alteration of the character of the surface A notable case of this kind occurred at Torquay, where a main about 14 miles long, composed of 14,267 yards of 10-inch, 10,085 yards of 9 inch, and 170 yards of 8-inch pipe, delivered only 317 gallons per minute, with 465 feet head We may calculate the

discharge by the method explained in (13)—Assuming 1000 gallons, we have by Table 3 —

Friction of 10-inch	=	04115 × 14267	= 587 1	feet head
„ 9 „	=	0697 × 10085	= 702 9	„ „
„ 8 „	=	1256 × 170	= 21 3	„ „
			1311 3	„ *total*

And from this, the discharge with the real head is $\frac{\sqrt{465} \times 1000}{\sqrt{1311\ 3}}$ or $\frac{21\ 564 \times 1000}{36\ 21} = 595$ gallons But by Prony's rule (32) the discharge comes out 616 gallons The experimental discharge was therefore only $\frac{317}{616} = 51$ or 51 per cent of the theoretical, or in round numbers the discharge was that due to $\frac{1}{4}$th of the head so that $\frac{3}{4}$ths of the head was lost in undue friction An ingenious scraper, suggested by the late Mr Appold, and worked by the pressure of the water, was passed through the entire length of the pipes, and subsequently an improved one by W Froude, Esq, was used with remarkable results, the discharge being increased to 564, and eventually, by repeated scraping, to 634 gallons, which is 18 gallons, or 3 per cent more than the theoretical quantity Errors of observation, or in the reputed sizes of the pipes, may account for the discrepancy

Dr Angus Smith s process, by which pipes are coated all over with a black enamel, seems to be an effective remedy against rusting, such pipes have been used with Torquay water for years without being affected The process is very cheap, being only about 5*s* per ton for medium pipes, it can be effectively applied only in the process of casting, while the pipes are new and hot With such a smooth surface as this process produces, the discharging power must be increased in a higher ratio than the cost, so that such pipes must really be more economical than any other

CHAPTER II.

ON FOUNTAINS, JETS, &c.

(38) "*Height of Jets with given Heads*"—When water issues vertically from a nozzle, as at J in Fig 5, it should theoretically attain the height of the head, and h should be equal to H, but it has been found by experiment that the height of the jet is always less than the head, a loss arising from the resistance of the air The difference, or h', is found to increase with the absolute height of the jet, and to diminish with an increase in the diameter There are very few reliable experiments on this subject, and the laws indicated by those we have are very intricate The best experiments we have are given in Table 7, and from them we find that h' increases nearly in the ratio of the square of the head, so that if we draw to scale the successive heights found by experiment, as in Fig 14, we obtain a curve which approximates to a parabola Thus, for a $\frac{1}{2}$-inch jet, as in the Figure, with 160 feet head, the jet would have attained the height B, or 160 feet, if there had been no resistance from the air, but it is found by experiment that it only reaches 80 feet as at D, therefore $h' = 80$ feet is lost. Again, with 80 feet head the jet should have reached C = 80 feet, but the experimental height is only 60 feet, and, in that case, $h = 20$ feet Thus with heads in the ratio of 1, 2, the loss is in the ratio 1^2, 2^2, or 1 to 4, being in fact 20 and 80 feet

(39) Experiment also shows, that the head being constant, h' varies nearly in inverse ratio to the diameter of the jet, for instance, we have just seen that with 80 feet head on the $\frac{1}{2}$-inch jet, 20 feet head is lost Then with a jet 1 inch diameter the loss would be about 10 feet, and the height attained 70 feet, but with a $\frac{1}{4}$-inch jet the loss would be about 40 feet, and the height attained 40 feet, &c Thus we have the elements for calculating approximately the loss of head for any particular case, not perfectly agreeing, perhaps, with the true law, but the best

TABLE 7.—OF EXPERIMENTS on the HEIGHT of JETS with DIFFERENT HEADS

Diam. of Jet in Inches.	Head on the Jet in Feet.	Height of Jet in Feet.		Error	Loss of Height by Jet in Feet.		
		Experiment.	Calculated		Experiment.	Calculated	
				feet.			
$2\frac{1}{2}$	365	284	282	−2 0	81	83	Chatsworth
$1\frac{5}{8}$	64	61	60 1	−0 9	3	3 9	Witley Court
,,	92	84	83 86	−0 14	8	8 14	,,
,,	115	103	102 3	−0 7	12	12 7	,,
1	445	109	136 0	+27 0	336	309	Torquay.
$\frac{3}{4}$	46	43	41 2	−1 8	3	4 8	Witley Court
,,	69	62	59 0	−3 0	7	10 0	,,
,,	92	77	74 4	−2 6	15	17 6	,,
,,	115	93	87 5	−5 5	22	27 5	,,
,,	141	98	99 6	+1 6	43	41 4	,,
,,	162	106	107 3	+1 3	56	54 7	,,
$\frac{5}{8}$	15	14 25	14 44	+0 19	0 75	0 56	Weisbach
,,	30	27 81	27 75	−0 06	2 19	2 25	,,
	45	39 42	39 94	+0 52	5 58	5 06	,,
,,	60	48 36	51 00	+2 64	11 64	9 00	,,
$\frac{3}{8}$	15	14 04	14 06	+0 02	0 96	0 94	,,
,,	30	26 44	26 25	−0 19	3 56	3 75	,,
,,	45	36 18	36 56	+0 38	8 82	8 44	,,
,,	60	42 96	45 00	+2 04	17 04	15 00	,,
,,	32	27	27 7	+0 7	5	4 3	Witley Court
,,	46	36	37 2	+1 2	10	8 8	,,
,,	95	55	57 4	+2 4	40	37 6	,,
,,	118	63	60 0	−3 0	55	58 0	,,
$\frac{3}{16}$	28 8	19	21 9	+2 9	9 8	6 9	,,
,,	64	30	30 0	0 0	34 0	34 0	,,

approximation we can obtain this is a subject on which more experimental information is very desirable Table 8 gives the height of jets with different heads, and is calculated by the following rule:—

$$h' = \frac{H^2}{d} \times \cdot 0125\,;$$

In which H = the head on the jet in feet.

„ h' = the difference between the height of head and height of jet

„ d = diameter of jet in $\frac{1}{8}$ths of an inch.

TABLE 8.—Of the HEIGHT of JETS with DIFFERENT HEADS.

Head on Jet in Feet.	DIAMETER OF JET IN INCHES.										
	⅛	¼	⅜	½	⅝	¾	1	1¼	1½	1¾	2
	HEIGHT OF JET IN FEET										
10	8·75	9·37	9·6	9·7	9·75	9·8	9·84	9·875	9 9	9·91	9·92
20	15·0	17·5	18·33	18·75	19·0	19·2	19·4	19·5	19·6	19·6	19·7
30	19·0	24·4	26·25	27·2	27·75	28·3	28·6	29·0	29·1	29·2	29 3
40	20·0	30·0	33·3	35·0	36·0	37·0	37·5	38·0	38·3	38 6	38 7
50	..	34·4	39·6	42·2	44·0	45·0	46·1	47·0	47·4	47·8	48·0
60	..	37·5	45·0	48·7	51·0	52·0	54·4	55·0	56·2	56·6	57·0
70	..	39·0	50·0	55·0	58·0	60·0	62·4	64·0	65·0	65·6	66·0
80	..	40·0	53 0	60·0	64·0	67·0	70·0	72·0	73·3	74·2	75·0
90	..	..	56·0	65·0	70·0	73 0	77·0	80 0	81·6	83·0	84 0
100	..	..	58·0	69	75	79	84	87	90	91	92
120	..	..	60·0	75	84	90	97	102	105	107	109
140	..	..	..	79	91	99	109	116	120	123	125
160	..	..	..	80	96	106	120	128	133	137	140
180	..	..	..	..	99	112	129	139	141	151	155
200	..	..	..	..	100	116	137	150	158	166	169
220	..	..	..	..	..	119	145	159	165	177	182
240	..	..	..	..	..	120	150	168	180	189	195
260	..	..	..	..	..	..	155	175	190	200	208
280	..	..	..	..	..	..	158	182	198	210	219
300	..	..	..	..	..	..	160	187	206	220	230
350	..	..	..	..	..	..	..	198	222	241	255
400	..	..	..	..	..	..	..	200	233	257	275

(40.) It is a result of this rule, that each particular size of jet attains its maximum height with a certain head, and that if the head is increased beyond that point, the height of jet is not increased thereby, but is actually diminished. This result is anomalous; it may be that an excessive head breaks the issuing stream into spray and causes it to meet with more resistance from the air than a jet of solid water issuing with a moderate head. Experiments with excessive heads show an enormous loss: thus a jet 1 inch diameter with 445 feet head, reached a height of about 109 feet only, as measured by a theodolite. Our rule gives the loss $h' = \frac{445^2}{8} \times \cdot 0125$, or $\frac{198025}{8} \times \cdot 0125$

TABLE 7.—Of EXPERIMENTS on the HEIGHT of JETS with DIFFERENT HEADS

Diam. of Jet in Inches.	Head on the Jet in Feet.	Height of Jet in Feet.		Error	Loss of Height by Jet in Feet.		
		Experiment	Calculated		Experiment.	Calculated	
				feet			
2½	365	284	282	−2 0	81	83	Chatsworth
1⅝	64	61	60 1	−0 9	3	3 9	Witley Court
,,	92	84	83 86	−0 14	8	8 14	,,
,,	115	103	102 3	−0 7	12	12 7	,,
1	445	109	136 0	+27 0	336	309	Torquay
¾	46	43	41 2	−1 8	3	4 8	Witley Court
,,	69	62	59 0	−3 0	7	10 0	,,
,,	92	77	74 4	−2 6	15	17 6	,,
,,	115	93	87 5	−5 5	22	27 5	,,
,,	141	98	99 6	+1 6	43	41 4	,,
,,	162	106	107 3	+1 3	56	54 7	,,
⅝	15	14 25	14 44	+0 19	0 75	0 56	Weisbach
,,	30	27 81	27 75	−0 06	2 19	2 25	,,
,,	45	39 42	39 94	+0 52	5 58	5 06	,,
,,	60	48 36	51 00	+2 64	11 64	9 00	,,
⅜	15	14 04	14 06	+0 02	0 96	0 94	,,
,,	30	26 44	26 25	−0 19	3 56	3 75	,,
,,	45	36 18	36 56	+0 38	8 82	8 44	,,
,,	60	42 96	45 00	+2 04	17 04	15 00	,,
,,	32	27	27 7	+0 7	5	4 3	Witley Court
,,	46	36	37 2	+1 2	10	8 8	,,
,,	95	55	57 4	+2 4	40	37 6	,,
,,	118	63	60 0	−3 0	55	58 0	,,
$\frac{3}{16}$	28 8	19	21 9	+2 9	9 8	6 9	,,
,,	64	30	30 0	0 0	34 0	34 0	,,

approximation we can obtain · this is a subject on which more experimental information is very desirable Table 8 gives the height of jets with different heads, and is calculated by the following rule —

$$h' = \frac{H^2}{d} \times \cdot 0125;$$

In which H = the head on the jet in feet

„ h = the difference between the height of head and height of jet

„ d = diameter of jet in $\frac{1}{8}$ths of an inch

TABLE 8 —Of the HEIGHT of JETS with DIFFERENT HEADS

Head on Jet in Feet.	Diameter of Jet in Inches.										
	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2
	Height of Jet in Feet										
10	8 75	9 37	9 6	9 7	9 75	9 8	9 84	9 875	9 9	9 91	9 92
20	15 0	17 5	18 33	18 75	19 0	19 2	19 4	19 5	19 6	19 6	19 7
30	19 0	24 4	26 25	27 2	27 75	28 3	28 6	29 0	29 1	29 2	29 3
40	20 0	30 0	33 3	35 0	36 0	37 0	37 5	38 0	38 3	38 6	38 7
50		34 4	39 6	42 2	44 0	45 0	46 1	47 0	47 4	47 8	48 0
60		37 5	45 0	48 7	51 0	52 0	54 4	55 0	56 2	56 6	57 0
70		39 0	50 0	55 0	58 0	60 0	62 4	64 0	65 0	65 6	66 0
80		40 0	53 0	60 0	64 0	67 0	70 0	72 0	73 3	74 2	75 0
90			56 0	65 0	70 0	73 0	77 0	80 0	81 6	83 0	84 0
100			58 0	69	75	79	84	87	90	91	92
120			60 0	75	84	90	97	102	105	107	109
140				79	91	99	109	116	120	123	125
160				80	96	106	120	128	133	137	140
180					99	112	129	139	141	151	155
200	..				100	116	137	150	158	166	160
220						119	145	159	165	177	182
240						120	150	168	180	180	105
260							155	175	190	200	-08
280							158	182	198	210	-10
300							160	187	206	2-0	-30
350								198	-2	211	-35
400		.						200	233	257	-75

(40) It is a result of this rule, that each particular size of jet attains its maximum height with a certain head, and that if the head is increased beyond that point, the height of jet is not increased thereby, but is actually diminished This result is anomalous it may be that an excessive head breaks the issuing stream into spray and causes it to meet with more resistance from the air than a jet of solid water issuing with a moderate head Experiments with excessive heads show an enormous loss thus a jet 1 inch diameter with 415 feet head, reached a height of about 100 feet only, as measured by a theodolite

Our rule gives the loss $h = \frac{415^2}{8} \times .012^2$, or $\frac{100045}{8} = .0195$

= 309 feet, and hence the height of jet is 445 – 309 = 136 feet The error of 27 feet is considerable, but perhaps not more than might be expected in such an extreme case

(41) "*Discharge of Jets*"—The quantity of water discharged will vary considerably with the *form* of the nozzle The form is also a matter of importance, as affecting the solidity of the issuing stream, and thereby the height of the jet Fig 15 shows the best form of nozzle, and Table 9 gives the general proportions

TABLE 9 —Of the PROPORTIONS of NOZZLES for JETS

A	B	C	D.
in	in.	in.	in.
$\frac{1}{4}$	45	6	3
$\frac{3}{8}$	67	9	45
$\frac{1}{2}$	90	1 2	6
$\frac{5}{8}$	1 12	1 5	75
$\frac{3}{4}$	1 35	1 8	9
1	1 80	2 4	1 2
$1\frac{1}{4}$	2 25	3 0	1 5
$1\frac{1}{2}$	2 70	3 6	1 8
$1\frac{3}{4}$	3 15	4 2	2 1
2	3 6	4 8	2 4
$2\frac{1}{4}$	4 0	5 4	2 7
$2\frac{1}{2}$	4 5	6 0	3 0
$2\frac{3}{4}$	4 9	6 6	3 3
3	5 4	7 2	3 6

for different sizes The lip at E projecting beyond the mouth is intended to protect the bore from indentation by accident The discharge by well made nozzles of this form will be about 913, the theoretical discharge being 1 0, and may be found direct by the following rule —

$$G = \sqrt{H} \times d^2 \times 21,$$

In which H = the head of water on the jet in feet.

d = the diameter in $\frac{1}{8}$ths of an inch

G = gallons discharged per minute.

Table 10 has been calculated by this rule

(42) "*Jets at the End of Long Mains*"—When a jet is placed at the end of a pipe, or series of pipes, as is usually the case,

.e 10.—Of the Discharge of Jets with Different Heads

	Diameter of Jet in Inches.												
	3/8	7/16	1/2	5/8	3/4	7/8	1	1¼	1½	1¾	2	2¼	2½
	Gallons Discharged per Minute.												
[illegible]	4 83	6 58	8 59	13 4	19 3	26 3	34 4	53·7	77 0	105	137	174	215
[illegible]	6 [illegible]	9 [illegible]	12 1	18 9	27 3	37 1	48 5	75 8	109	148	194	244	303
[illegible]	[illegible]	11 4	14 8	23 2	33 4	45 5	59 4	92 9	134	182	238	301	372
[illegible]	9 [illegible]	13 0	17 2	26 8	38 6	52 6	68 6	107	154	210	274	347	429
[illegible]	10 8	14 7	19 2	30 0	43 2	58 8	76 8	120	173	235	307	389	480
[illegible]	11 [illegible]	16 1	21 0	32 8	47 3	64 4	81 1	131	189	258	336	426	525
[illegible]	12 [illegible]	17 4	22 7	35 5	51 1	69 6	90 9	142	204	278	364	460	568
[illegible]	[illegible]	18 6	24 7	37 9	54 6	74 3	97 1	152	218	297	388	491	609
[illegible]	14 5	20 2	25 [illegible]	40 3	58 0	80 7	103	161	232	323	412	522	644
[illegible]	15 2	21 3	27 1	42 4	61 1	84 9	109	170	244	340	434	550	680
[illegible]	[illegible] 7	22 [illegible]	29 7	46 4	66 9	91 1	119	186	267	364	476	602	744
[illegible]	[illegible]	24 5	[illegible] 1	50 1	72 3	98 4	129	201	289	393	514	650	803
[illegible]	[illegible] 3	[illegible] 3	[illegible] 3	53 6	77 2	105	137	215	309	421	549	695	858
[illegible]	[illegible] 5	[illegible]	[illegible] 4	[illegible] 9	82 0	111	145	227	328	446	593	738	910
[illegible]	21 6	[illegible] 4	[illegible] 4	60 0	86 4	117	153	240	346	471	615	778	960
[illegible]	22 [illegible]	[illegible]	[illegible] 3	[illegible] 9	90 6	123	161	252	362	493	644	815	1010
[illegible]	[illegible]	[illegible] 6	42 0	[illegible] 7	94 6	130	168	263	378	522	673	852	1052
[illegible]	[illegible]	[illegible] 5	[illegible] 7	[illegible] 4	[illegible] 5	134	175	273	394	536	700	886	1094
[illegible]	[illegible]	[illegible]	[illegible] 4	71 0	102	139	181	284	409	557	727	920	1136
[illegible]	[illegible] 4	[illegible] 0	[illegible] 0	[illegible] 5	[illegible]	144	188	294	423	576	752	952	1176
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] 4	114	[illegible]	203	317	457	624	813	1029	1270
[illegible]	[illegible]	[illegible] 5	54 3	[illegible]	[illegible]	[illegible]	217	[illegible]	490	665	869	1099	1358
[illegible]	[illegible] 1	40 5	[illegible] 7	[illegible]	[illegible]	[illegible]	243	379	546	744	971	1230	1518
[illegible]	[illegible] 4	50 1	66 5	104	[illegible]	[illegible]	[illegible]	415	598	816	1064	1316	1663

calculation must be made of the loss of head by friction in such pipes, so as to obtain the actual head *on the jet*, for which alone the rules and Table apply Say, for illustration, we take the case, shown by Fig 16, of a jet 1 inch diameter, 70 feet high, at the end of a long main 6 inches, 5 *inches, and* 4 *inches* diameter, of the respective lengths given by the Figure, and that we have to calculate the head necessary Table 8 shows that a jet 1 inch diameter, 70 feet high, requires 80 feet head, and Table 10 gives the discharge of the same jet, with 80 feet head, at 137 gallons Then, by Table 3, we calculate the friction of the mains, and we have the following results —

				Feet.
Head to play 1 inch jet 70 feet high			=	80 00
Friction 6 inch main, say 140 gallons	=	01037 × 600	=	6 22
" 5 " "	=	0258 × 300	=	7 74
" 4 " "	=	0788 × 100	=	7 88
			Total =	101 84

(43) In other cases we may have the head and diameter of pipes and nozzle given, and have to determine the discharge This case is illustrated by Fig 17, and in dealing with it, we must follow the course indicated in (13) Say we assume the discharge at 300 gallons, Table 10 shows that a jet 1½ inch diameter requires *about 75 feet head for that quantity* Then, by Table 3, we find the friction of the mains as follows —

				Feet.
Head to play 1½ inch jet 300 gallons			=	75 00
Friction 7 inch main, 300 gallons	=	022 × 800	=	17 60
" 6 "	=	0476 × 400	=	19 04
" 5 " "	=	1185 × 80	=	9 48
			Total =	*121 12*

So that for our assumed discharge of 300 gallons we require only *121 12 feet, instead of 150, the head at disposal* Then by the rule in (13) the true discharge with 150 feet head will be $\frac{300 \times \sqrt{150}}{\sqrt{121\ 12}} = 334$ gallons. In such cases as this, where the height of a jet *is involved, the discharge assumed should be pretty* near the true one

(44) In another case we might require to find the diameter of one of the main pipes, having all the rest given Thus, say that we have to find the diameter of the pipe P, in Fig 18 Table 8 gives 90 feet as the head for $1\frac{1}{4}$ jet 80 feet high, and Table 10 gives 227 gallons as the discharge of the same jet with 90 feet head.

Then, $1\frac{1}{4}$ jet 80 feet high, by Table 8	90 0 feet head
Friction of 6 inch main = 028 × 400	11 2 „
	101 2 „

We have therefore 115 − 101 2 = 13 8 feet of head left for the friction of the pipe P, or $\frac{13\ 8}{200}$ = 069 foot per yard, which by Table 3 is equal to a 5 inch pipe with say 230 gallons, and this is the required diameter of the pipe P

(45) ' *Path of Fountain Jets* —When the discharge takes place obliquely, or out of the perpendicular, the path of the jet is a parabola, and may be conveniently described by the method shown in Fig 23, in which we have a jet discharging upward at an angle of 45°, and with a head of 14 feet which by Table 11 will give a velocity of 30 feet per second, or 3 feet per tenth of a second If we mark on the line S, E a series of points A, B, C, &c, 3 feet apart, they would show the position of a particle of water at each tenth of a second if gravity did not act but of course gravity does act simultaneously, and Table 12 gives the space fallen through each tenth of a second, which being plotted on the perpendiculars drawn through each of the points A, B C &c, will give the true position of the particle of water at each tenth of a second Thus in $\frac{3}{10}$ths of a second it would have arrived at C, if uninfluenced by gravity, but the Table shows that in that time a body falls 1 foot $5\frac{1}{4}$ inches, therefore F is the true position at that moment, and so of the rest, as in the Figure, which gives the path for two seconds The lower curve S, T in Fig 23, shows the path of a jet with the same head and velocity projected *downwards* at the same angle of 45° Fig 19 gives the path for a horizontal projection, and also

TABLE 11.—FALLING BODIES, giving the SPACE fallen through to acquire certain VELOCITIES.

Velocity in Feet per Second.	Space. ft.	Space. ins.	Velocity in Feet per Second	Space. ft.	Space. ins.	Velocity in Feet per Second.	Space. ft.	Space. ins.
1	0	0 3/16	21	6	10	41	26	1
2	0	0 3/4	22	7	6	42	27	5
3	0	1 5/8	23	8	3	43	28	9
4	0	3	24	9	0	44	30	1
5	0	4 5/8	25	9	9	45	31	5
6	0	6 3/4	26	10	6	46	32	10
7	0	9 1/8	27	11	4	47	34	4
8	1	0	28	12	3	48	36	10
9	1	3 1/4	29	13	0	49	37	4
10	1	6 3/4	30	14	0	50	38	11
11	1	10 1/3	31	14	11	52	42	0
12	2	3	32	15	11	54	45	4
13	2	7 3/8	33	16	11	56	50	0
14	3	0 3/4	34	18	0	58	52	0
15	3	6	35	19	0	60	56	0
16	4	0	36	20	1	62	59	8
17	4	6	37	21	5	64	63	8
18	5	0	38	22	6	66	67	8
19	5	7	39	23	9	68	72	0
20	6	3	40	24	11	70	76	0

TABLE 12.—FALLING BODIES

Time Seconds.	Whole Space fallen ft.	Whole Space fallen ins.	Velocity acquired. Feet per Second. ft.	Time. Seconds.	Whole Space fallen. ft.	Whole Space fallen. ins.	Velocity acquired. Feet per Second. ft.
1/10	0	1 15/16	3 2	1 1/10	19	4 3/8	35 2
2/10	0	7 5/8	6 4	1 2/10	23	0 1/2	38 4
3/10	1	5 1/4	9 6	1 3/10	27	0 1/4	41·6
4/10	2	6 3/4	12·8	1 4/10	31	[illegible]	44·8
5/10	4	0	16 0	1 5/10			48 0
6/10	5	9 1/6	19 2	1 6/10			51·2
7/10	7	10	22 4	1 7/10			54 4
8/10	10	2 7/8	25 6	1 8/10			57·6
9/10	12	11 1/2	28 8	1 9/10			
1	16	0	32 0	2			

illustrates another method of drawing the parabolic curve, which consists in dividing the total space fallen through J, K into the same number of equal parts as the line H, J, and drawing radial lines from the point H, as shown The path of the jet is through the intersections of the radial lines with the perpendiculars, as in the figure the two methods give the same result precisely

(46) There are some general laws governing the parabolic paths of jets which it will be well to state explicitly Let Fig 20 be a jet playing obliquely from a nozzle at J, and striking the horizontal plane at G

1st If the line of direction of the pipe or axis of the jet be prolonged, it cuts the axis of the parabola at a point C, whose distance from the base is always double the height of the parabola, or C N is equal to twice D N This gives a useful rule for finding the proper angle of the jet pipe when the path of the jet has been determined.

2nd If we find the focus of the parabola by the ordinary method, namely, by bisecting the radius of the base at A, drawing the line A D, and making A L perpendicular to A D, then the point L is the focus of the parabola and the distance N L is the *extra* head h necessary to play the jet horizontally, or the difference between the maximum height of the jet and the head upon it at J Thus the total head H may be considered as divided into two portions, namely, H, which is equal to the height of the parabola D N, and h, which is equal to the distance of the focus of the parabola from the base

3rd If, therefore, with the same head the jet were made to play vertically, it would (theoretically) attain the height of H, instead of H

4th In all cases, h bears a certain proportion to the height of the parabola (H), and to the length of its base B, and may be calculated from those particulars by the rule $h = \frac{(\frac{1}{4}B)^2}{H}$, thus, to play a jet 32 feet horizontally (B), and 16 feet high (H), as in Fig 21, we shall have $h = \frac{8^2}{16} = 4$ feet, which, added to the

height of the jet path (16 feet), gives 20 feet for the total head on the jet

5th The horizontal distance from the nozzle at J to the point on the plane at G, where the jet strikes it, may be calculated when the total head H and the height of the parabola H are given, for obviously $H - H = h$, and knowing h, we may find B by the rule $\sqrt{h \times H} \times 4 = B$ Thus, in Fig 21, we have $H' = 20$, and $H = 16$, therefore, $h = 20 - 16 = 4$, and then $\sqrt{4 \times 16} \times 4 = 32$ feet

6th When the jet issues horizontally, as in Fig 25, its path is half a parabola, following the same laws as before, namely, $h = F$, also $h = \dfrac{(\frac{1}{2} P)^2}{H}$, and $\sqrt{h \times H} \times 2 = P$, &c

(47) In some cases, the two half parabolas are unequal, as in Fig 24, where we have a jet 20 feet high at its maximum, delivering at N = 15 feet high, and 24 feet distant horizontally from the nozzle at J, and we require to find $h =$ the extra head, and to describe the path of the jet Here we have first to find the position of the centre line dividing the semi-parabolas, and to do this we have $\dfrac{D \times \sqrt{H}}{\sqrt{H} + \sqrt{H}} = R$, which in our case becomes $\dfrac{24 \times 4\ 472}{4\ 472 + 2\ 236} = 16$ feet Then the focus of the two semi parabolas may be found as before, and it will be found that F and F are equal Thus, in our case $F = \dfrac{\left(\frac{16}{2}\right)^2}{20} = 3\ 2$ feet and $F = \dfrac{\left(\frac{8}{2}\right)^2}{5} = 3\ 2$ feet also F being equal to h, we thus find h to be 3 2 feet, and the total head at J will therefore be $20 + 3\ 2 = 23\ 2$ feet (H) If we reverse the direction of the jet, placing the nozzle at N, instead of at J, then, with a head of $5 + 3\ 2 = 8\ 2$ feet, the path of the jet would be the same as before

(48) We have followed throughout the investigation of the paths of oblique jets, the theoretical law that the height of the jet is equal to the head, and we have done this to avoid complicating the matter unnecessarily; but obviously, we must apply to oblique jets the correction we found necessary for perpendicular ones. Thus, if we had a jet ½-inch diameter, with 80 feet head, Table 8 shows that the height attained vertically would be only 60 feet, and if this jet played obliquely, its path should be calculated for the latter height, but the quantity of water expended, and the value of *h* must be calculated for 80 feet.

Oblique jets of great height and range, deviate considerably from the true parabolic path assigned by the rules, the curve becomes in such cases like A, D, E in Fig 22, the true parabolic path being A, B, C. But for moderate heights and ranges, such as usually occur in practice, the deviation is not considerable.

(49) "*Ornamental Jets*"—There are many kinds of ornamental jets which may be used with pleasing effect in *very sheltered* situations, especially in the interior of conservatories, &c. One of these, called the "Convolvulus," from the form of its display, is shown in half-size section by Fig 26. The pressure of a very small head of water (2 or 3 feet) raises the valve B, and allows a thin sheet of water to escape, forming a sheet jet of the form given in Fig 27, and (with the size given by Fig 26) about 3 feet diameter, with an expenditure of about 6 gallons per minute.

Fig 28 is a half-size section of the "Dome" or "Globe" jet, which produces a display of the form shown by Fig 29, with a head of about 2 feet, the globe being about 14 inches diameter, and the expenditure about 3 gallons per minute. With a greater head say 3 or 4 feet, the display has the form of an umbrella about 21 inches diameter, expending about 4 gallons per minute.

The "Basket and Ball" jet is another pleasing variety, the basket is of fancy wire-work, large enough to catch the ball when it escapes from the jet of water, and formed so as to return it back to its place. The ball is formed of light wood (lime-tree is the best), painted or gilded, and well varnished

There should be a certain proportion between the size of the ball and the diameter of the jet. As an approximation we may give the following rule —

$$\sqrt[3]{d^2 \times 1 \cdot 3} = D,$$

In which d = the diameter of the jet in $\frac{1}{8}$ths of an inch.
D = the diameter of the ball in inches.

Table 13 has been calculated by this rule; it gives the proportions up to 1-inch jets, but the $\frac{3}{4}$-inch jet, with $3\frac{1}{2}$-inch ball is usually the maximum size in practice.

TABLE 13.—FOR BALL JETS.

Diameter of Jet.		Diameter of Ball.
$\frac{1}{8}$-inch	=	$1\frac{1}{8}$-inch
$\frac{1}{4}$ "	=	$1\frac{3}{4}$ "
$\frac{3}{8}$ "	=	$2\frac{1}{4}$ "
$\frac{1}{2}$ "	=	$2\frac{3}{4}$ "
$\frac{5}{8}$ "	=	$3\frac{1}{8}$ "
$\frac{3}{4}$ "	=	$3\frac{1}{2}$ "
$\frac{7}{8}$ "	=	4 "
1 "	=	$4\frac{3}{8}$ "

CHAPTER III.

ON CANALS, CULVERTS, AND WATER-COURSES.

(50.) "*Open Water-courses*"—The discharge of open water-courses may be found experimentally by observing the velocity of the current and measuring the cross sectional area of the stream. But to do this correctly we require the *mean* velocity throughout the section, which is not given by observation. The velocity varies, being a maximum at the surface and where the channel is deepest, which is usually near the centre of the width, diminishing from thence to the banks on either side, and to the bottom, where it is a minimum.

The best experiments we have, give the mean velocity

throughout the section at 84 per cent. of the maximum central surface velocity, which is usually the velocity observed, being easily obtained by a float on the surface of the stream (68) Table 14 gives the mean velocity corresponding to observed maximum velocities; thus, if a channel whose area is 24 square feet, has by observation a central surface velocity of 35 feet per minute, the mean velocity by the Table is 29·4 feet, and the discharge will be 29·4 × 24 = 705·6 cubic feet, or 705 6 × 6·23 = 4396 gallons per minute.

TABLE 14.—For OPEN CHANNELS, CANALS, and RIVERS, giving the MEAN VELOCITY throughout the SECTION, corresponding to observed CENTRAL SURFACE VELOCITIES.

Surface Velocity	Mean Velocity	Surface Velocity	Mean Velocity	Surface Velocity	Mean Velocity	Surface Velocity	Mean Velocity
1	·84	26	21 84	51	42 84	76	63 84
2	1 68	27	22 68	52	43 68	77	64 68
3	2 52	28	23 52	53	44 52	78	65 52
4	3 36	29	24 36	54	45 36	79	66 36
5	4 2	30	25 2	55	46 20	80	67 2
6	5 04	31	26 06	56	47 04	81	68 04
7	5 88	32	26 88	57	47 88	82	68 88
8	6 72	33	27 72	58	48 72	83	69 72
9	7 56	34	28 56	59	49 56	84	70 56
10	8 4	35	29 4	60	50 4	85	71 40
11	9 24	36	30 24	61	51 24	86	72 24
12	10 08	37	31 08	62	52 12	87	73 08
13	10 92	38	31 92	63	52 92	88	73 92
14	11 76	39	32 76	64	53 76	89	74 76
15	12 60	40	33 6	65	54 6	90	75 6
16	13 44	41	34 44	66	55 44	91	76 44
17	14 28	42	35 28	67	56 28	92	77 28
18	15 12	43	36 12	68	57 12	93	78 12
19	15 96	44	36 96	69	57 96	94	78 96
20	16 8	45	37 8	70	58 8	95	79 80
21	17 64	46	38 64	71	59 68	96	80 64
22	18 48	47	39 48	72	60 48	97	81 48
23	19 32	48	40 32	73	61 32	98	82 32
24	20 16	49	41 16	74	62 16	99	83 16
25	21 0	50	42 0	75	63 00	100	84 00

(51) "*Head due to Velocity in Open Channels*"—When a stream leaves the still water of a lake or reservoir, as in Fig 30,

at a given velocity, there will be a certain loss of head to generate that velocity, that is to say, the stream at F must be lower than the still water at E in order to create the velocity required at G In a case like the Figure, the bottom of the channel at F being at the same level as the bottom of the reservoir at E, and with a well-rounded entrance, the velocity would be 96 of that due to gravity, and the same co-efficient would apply to the waterway of a sluice-gate, like Fig 31, if the gate is drawn up completely out of the water and to the openings of a bridge with pointed piers, as at Fig 32, the conditions being evidently similar in all the three cases With similar conditions, but with square corners at the sides of the inlet opening, as in Fig 34, the bottom of the channel being still at the same level as that of the reservoir, the velocity at G would be 86 of that due to gravity, or to the difference of level between E and F, and the same co-efficient applies to the openings of a bridge with square piers as in Fig 33

With an opening in a sluice-gate of small thickness, as at Fig 35 the head of water being above the lower edge of the gate the velocity is only 635 of that due to gravity, a contraction (2) occurring on all the four sides of the aperture If the gate be fully drawn up, the opening becomes a weir, as at Fig 36, then contraction occurs on three sides only, and the co-efficient rises to 667 These co-efficients are given by Eytelwein, and Table 15 gives the velocities for different heads calculated by them

(52) "*Head to overcome Friction of Channel*"—When the channel is a long one, there is not only a loss of head due to the velocity, but also a further loss by friction against the sides and bottom Where the channel is of equal cross sectional area from end to end, the loss of head increases uniformly from end to end, and the surface of water has a certain slope or fall per yard or per mile Fig 37 shows the section of a water-course in which the fall from the still water in the reservoir at A to the point B is due to the velocity at B, and this would be the same whatever the length of the channel, its amount varies with the form of the entrance as explained in (51) From B to

C there will be a regular slope when the area of the channel is uniform, and the fall C D is due to friction for the length B C

TABLE 15 —Of the VELOCITIES in FEET per SECOND, due to given HEADS

Head in Inches.	A. Coef. 1 0.	B Coef. 96	C Coef. 86.	D Coef. 635	Head in Inches.	A. Coef. 1 0	B Coef. 96	C Coef. 86.	D Coef 635
$\frac{1}{64}$	29	2784	2494	18415	1	2 317	2 2224	1 9930	1 4713
$\frac{1}{32}$	41	3936	3524	2603	$1\frac{1}{4}$	2 590	2 4861	2 2270	1 6116
$\frac{1}{16}$	58	5568	4988	3683	$1\frac{1}{2}$	2 837	2 7235	2 43 3	1 8015
$\frac{1}{8}$	82	7872	7052	5207	$1\frac{3}{4}$	3 065	2 9424	2 6369	1 9463
$\frac{3}{16}$	1 0	9600	8600	6350	2	3 276	3 145	2 8174	2 0803
$\frac{1}{4}$	1 158	1 1117	99 9	7353	$2\frac{1}{4}$	3 475	3 336	2 9885	2 2066
$\frac{5}{16}$	1 295	1 2132	1 1140	8223	$2\frac{1}{2}$	3 663	3 516	3 1502	2 3260
$\frac{3}{8}$	1 418	1 3613	1 2195	9001	$2\frac{3}{4}$	3 842	3 688	3 3041	2 4397
$\frac{7}{16}$	1 532	1 4707	1 3175	9728	3	4 012	3 851	3 4503	2 5476
$\frac{1}{2}$	1 638	1 5725	1 4087	1 0101	$3\frac{1}{4}$	4 176	4 009	3 5914	2 6517
$\frac{9}{16}$	1 737	1 6675	1 4938	1 1030	$3\frac{1}{2}$	4 334	4 161	3 7272	2 7521
$\frac{5}{8}$	1 831	1 7577	1 5747	1 1627	$3\frac{3}{4}$	4 486	4 306	3 8580	2 8486
$\frac{11}{16}$	1 921	1 8442	1 652	1 2198	4	4 633	4 448	3 9844	2 9420
$\frac{3}{4}$	2 006	1 9258	1 725	1 2738	$4\frac{1}{2}$	4 914	4 717	4 2260	3 1204
$\frac{13}{16}$	2 088	2 0045	1 796	1 3259	5	5 180	4 973	4 455	3 2893
$\frac{7}{8}$	2 167	2 0803	1 863	1 376	$5\frac{1}{2}$	5 433	5 216	4 672	3 450
$\frac{15}{16}$	2 213	2 1533	1 929	1 424	6	5 675	5 448	4 881	3 6036

(53) This fall may be calculated by the following rule —

$$F = \frac{\left(\frac{C}{A}\right)^2 \times L \times P}{874520 \times A},$$

In which L = length of the channel in yards
A = cross sectional area of the stream in square feet
P = the perimeter, or wetted border in feet
F = the fall, or difference of level at the two ends of the channel in inches
C = cubic feet discharged per minute

Thus, in the case shown by Fig 38, A being 6 × 2 5 = 15 square feet, P = 2 5 + 6 + 2 5 = 11 feet, say that with such a channel 1760 yards, or one mile long, we require the fall to

discharge 1105 cubic feet per minute then by the rule we have in our case $\dfrac{\left(\dfrac{1105}{15}\right)^2 \times 1760 \times 11}{874520 \times 15} = 8$ inches fall

(54) To this has to be added the head for the velocity at entry, or A B in Fig 37 The *mean* velocity being $\frac{1105}{15} =$ 73 66 feet, the maximum (50) will be $\frac{73\ 66}{\cdot 84} = 87\ 7$ feet per minute, or 1 46 foot per second, the head for which, with square corners, is given by Col C of Table 15 at about $\frac{1}{2}$-inch Then for a channel one mile long, the total head will be $8 + \frac{1}{2} = 8\frac{1}{2}$ inches, for $\frac{1}{8}$th of a mile, or 220 yards, $1 + \frac{1}{2} = 1\frac{1}{2}$ inch, and for 110 yards, $\frac{1}{2} + \frac{1}{2} = 1$ inch In the last case the head for velocity is equal to the head for friction

(55) When the fall is given, and the discharge has to be calculated the rule becomes —

$$C = \left(\frac{874520 \times F \times A}{L \times P}\right)^{\frac{1}{2}} \times A$$

Thus, with the same channel as before, 1760 yards long, and a fall of 12 inches, the discharge would be $\left(\frac{874520 \times 12 \times 15}{1760 \times 11}\right)^{\frac{1}{2}}$ $\times 15 = 1353$ cubic feet per minute We have omitted in this case to allow for the head due to velocity, and where the channel is a long one, the omission will not cause a serious error, with short channels, however, it must not be neglected

(56) When, with a given total head, we have to calculate the discharge by a channel so short that the head for velocity has to be considered as well as that due to friction, the question does not admit of a direct solution, because we cannot tell beforehand in what proportions the head at disposal has to be divided between the two The best course in that case is to assume a discharge, and calculate, as in (53) and (54) the head for friction and the head for velocity with that discharge Then

applying the law (27) that the discharges are directly proportional to the square roots of the respective heads, we may obtain the true discharge with the given head. Thus say that with the channel (Fig. 88) 50 yards long, the *total* head at disposal was 2 inches, and that we have to calculate the discharge. Say we assume it at 1000 cubic feet; then the head for friction would be

$$\frac{\left(\frac{1000}{15}\right)^2 \times 50 \times 11}{874520 \times 15} = \cdot 185 \text{ inch.}$$

The mean velocity being $\frac{1000}{15} = 65\cdot 7$, the maximum will be $\frac{65\cdot 7}{\cdot 84} = 78\cdot 8$ feet per minute, or $1\cdot 32$ feet per second, the head for which by Col. C in Table 15 is about $\frac{1}{27}$ or $\cdot 437$ inch; the total head for 1000 cubic feet is, therefore, $\cdot 185 + \cdot 437 = \cdot 622$ inch; hence the discharge with 2 inches head would be

$1000 \times \sqrt{2}$ $1000 \times 1\cdot 414$

The use of this Table may be illustrated by the following examples —Say we calculate by it the discharge of the channel (Fig 38) with a fall of 12 inches per mile as in (55) The hydraulic radius in our case is $\frac{15}{11} = 1\ 363$ foot, the nearest radii to which in the Table we find to be 1 3 and 1 4, and the corresponding velocities under the fall of 12 inches per mile are 88 1 and 91 4 respectively, interpolating between those numbers for our radius 1 363 we find the mean velocity to be about 90 2 feet, and the discharge $90\ 2 \times 15 = 1353$ cubic feet per minute

Again, to find the fall with the same channel 800 yards long for 1230 cubic feet per minute —The mean velocity being $\frac{1230}{15} = 82$ feet per minute, we look between 1 3 and 1 4 radii in the Table for that velocity, and we find it to be under the fall of 10 inches per mile, or 00568 inch per yard, hence the fall in our case is about $00568 \times 800 = 4\ 54$ inches for friction alone, or C D in Fig 37

(58) Take another case, shown by Fig 40, of an open cutting with sloping banks, and say that we require the discharge with a fall of 8 inches per mile The area being $\frac{30 + 20}{2} \times 2\ 5 = 62\ 5$ square feet, and the border $5\ 6 + 20 + 5\ 6 = 31\ 2$ feet the hydraulic radius is $\frac{62\ 5}{31\ 2} = 2$, which, by Table 30, with a fall of 8 inches per mile will have a velocity of 89 2 feet, and a discharge of $89\ 2 \times 62\ 5 = 5575$ cubic feet per minute

(59) "*River Channels of irregular Cross section*" —The application of the rules to the discharge of a stream of the natural irregular form of section may be illustrated by Fig 41 We found in (68) that the area was 27 74 square feet, taking say 2 feet in the compasses, and stepping along the border, we find it to measure about 21 5 feet the hydraulic radius is therefore, $\frac{27\ 74}{21\ 5} = 1\ 132$ foot Then, with a fall of say 10 inches per

mile, Table 30 gives, opposite the radius of 1·1 (which is the nearest to the one we require), the mean velocity of 73 9 feet per minute, hence the discharge is 73 9 × 27 74 = 2050 cubic feet per minute. With a very short channel, allowance should be made for velocity at entry, as explained in (56)

Table 30 may also be applied to the calculation of the discharge, &c., of common pipes running full, or to those of a square or other section, for an illustration of which see (36), also to culverts, &c., partially filled, see (62)

(60) "*Openings of Bridges, &c*"—The head lost by a stream in passing through a bridge is principally that due to velocity alone, the length of the channel being in most cases so short as to have little influence on the discharge The head for velocity may be calculated by Table 15 say we take the case (58) of the stream (Fig 40) discharging 5575 cubic feet per minute, and passing through an opening at a bridge, say 8 feet wide and 3 feet deep The area being 8 × 3 = 24 square feet, the velocity will be $\frac{5575}{24 \times 60} = 3\ 87$ feet per second, which, with pointed piers (Fig 32) will require by Col B of Table 15, 3 inches head (A, B in Fig 37) But, the stream approaches the bridge with a mean velocity of 89 2 feet, or a maximum (50) of $\frac{89\ 2}{84}$ = 106 feet per minute, or 1 77 foot per second, the head due to which by the same Table is $\frac{5}{8}$ inch The head at the bridge is, therefore, reduced to $3 - \frac{5}{8} = 2\frac{3}{8}$ inches, with square piers (Fig 33), the head by Col C is $3\frac{3}{4}$ inches, or at the bridge $3\frac{3}{4} - \frac{5}{8} = 3\frac{1}{8}$ inches.

(61) "*Submerged Openings*"—The velocity of discharge through a submerged opening A (Fig 43) is governed by the *difference* of the level of water at the two sides of it or by H, and is not affected by the depth below the surface at which it is placed. Table 15 will give the velocity with small heads thus an aperture 2 feet × 1 5 foot = 3 square feet area, and with H = *5 inches, would, by Col D of Table 15, discharge* 3 2893 × 3 = 9 87 cubic feet per second

TABLE 10.—Of the PROPORTIONS and DISCHARGING POWER of OVAL CULVERTS.

Total Height.	Width at the Top.	Radius of the Top.	Radius of the Bottom.	Radius of the Sides.	⅔ths full of Water, to the line A in Fig. 44. Depth of Water.	⅔ths full: Area in Square Feet.	⅔ths full: Hydraulic Radius in Feet.	⅓rd full of Water, to the line B in Fig. 44. Depth of Water.	⅓rd full: Area in Square Feet.	⅓rd full: Hydraulic Radius in Feet.
ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.			ft. in.		
2 0	1 4	0 8	0 4	2 0	1 8	1·732	·412	1 4	1·303	·367
3 0	2 0	1 0	0 6	3 0	2 6	3·890	·663	2 0	2·932	·550
4 0	2 8	1 4	0 8	4 0	3 4	6·928	·884	2 8	5·213	·733
5 0	3 4	1 8	0 10	5 0	4 2	10·82	1·105	3 4	8·145	·917
6 0	4 0	2 0	1 0	6 0	5 0	15·58	1·326	4 0	11·73	1·101
7 0	4 8	2 4	1 2	7 0	5 10	21·22	1·517	4 8	15·96	1·283
8 0	5 4	2 8	1 4	8 0	6 8	27·71	1·768	5 4	20·85	1·467
9 0	6 0	3 0	1 6	9 0	7 6	35·07	1·989	6 0	26·40	1·617
10 0	6 8	3 4	1 8	10 0	8 4	43·30	2·210	6 8	32·60	1·830

This shows that in all cases where extreme accuracy is desired, the rule in (61) should be used, but that where the fall exceeds 8 or 10 inches per mile, Table 30 gives results sufficiently correct for most practical purposes

(66) When the discharge is given, to determine the fall, the rule becomes

$$F = \frac{\left(\left(\frac{C}{A} + 6{\cdot}534\right)^2 - 42\ 8\right) \times L \times P}{896100 \times A}$$

Thus the fall for friction with the same channel, Fig 40, 2000 yards long to deliver 3000 cubic feet per minute would be

$$\frac{\left(\left(\frac{3000}{62\ 5} + 6\ 534\right)^2 - 42\ 8\right) \times 2000 \times 31\ 2}{896100 \times 62\ 5} = 3\ 26, \text{ or } 3\tfrac{1}{4} \text{ inches.}$$

Adding the head due to velocity at entry (51), the mean velocity is $\frac{3000}{62\ 5} = 48$, and the maximum $\frac{48}{84} = 57$ feet per minute, or ·95 foot per second, the head for which by Col C of Table 15 is about $\frac{1}{4}$ inch, the total head is therefore $3\frac{1}{4} + \frac{1}{4} = 3\frac{1}{2}$ inches

(67) Table 18 has been calculated by the following modification of Eytelwein s rule —

$$\frac{(V + 1089)^2 - 0118858}{8975} = R\ S$$

In which V = the mean velocity over the whole area in feet per second

R = the hydraulic radius in feet, or $\frac{\text{area in square feet}}{\text{border in feet}}$

S = the slope, or $\frac{\text{fall in inches}}{\text{length in inches}}$

By this Table approximately correct results may be obtained with less labour than by the rules

1st To find the Velocity —Multiply the area of the channel in square feet by the fall in inches, and divide the product by the border in feet multiplied by the length of the channel in inches find the nearest number thereto in Col B of Table 18, and oppo-

$$C = \left(\frac{896400 \times F \times A}{L \times P} + 42\ 8\right)^{\frac{1}{2}} - 6\ 534\Big) \times A,$$

In which L = length of the channel in yards
„ A = cross sectional area of the stream in square feet
„ P = the perimeter, or border of the channel in feet
„ F = the fall, or difference of level at the two ends of the channel in inches
„ C = cubic feet discharged per minute

(65) Thus, say that we require the discharge by the channel, Fig 40, 1 mile long, with a fall of 1 inch only, then L = 1760, A = 62 5, P = 31 2, as in (58), and F = 1, and the discharge will be $\left(\frac{896400 \times 1 \times 62\ 5}{1760 \times 31\ 2} + 42\ 8\right)^{\frac{1}{2}} - 6{\cdot}534) \times 62\ 5 = 1629\ 3$ cubic feet per minute. We may compare this result with that given by the rule in (55), by which the discharge comes out $\left(\frac{874520 \times 1 \times 62\ 5}{1760 \times 31\ 2}\right)^{\frac{1}{2}} \times 62\ 5 = 1972$ cubic feet per minute $= \frac{1972}{1629} = 1\ 21$, *or 21 per cent difference* *But with an increased* head, the difference becomes less, and is reduced practically to nothing with large heads, as shown by Table 17

TABLE 17 —Of the DISCHARGE of an OPEN CHANNEL, Fig 40, calculated by DIFFERENT RULES

Fall in Inches per Mile	Calculated Discharge. By Rule in (64)	By Rule in (55)	Difference per Cent.	By Table 30. Velocity	Area.	Discharge.
1	1629	1972	21 0	31 5 ×	62 5 =	1969
2	2444	2788	14 1	44 6	,,	2788
3	3073	3416	11 1	54 6	,,	3413
4	3556	3943	10 9	63 0	,,	3938
5	4074	4409	8 2	70 5	,,	4406
6	4499	4830	7 3	77 2	,,	4825
8	5233	5577	6 2	89 2	,,	5575
10	5918	6235	5 3	99 7	,,	6231
12	6519	6831	4 9	109 2	,,	6825
24	9380	9649	3 0	154 4	,,	9650
36	11576	11831	2 2	189 1	,,	11819

This shows that in all cases where extreme accuracy is desired, the rule in (64) should be used, but that where the fall exceeds 8 or 10 inches per mile, Table 30 gives results sufficiently correct for most practical purposes

(66) When the discharge is given, to determine the fall, the rule becomes

$$F = \frac{\left(\left(\frac{C}{A} + 6\ 534\right)^2 - 42\ 8\right) \times L \times P}{896400 \times A}$$

Thus the fall for friction with the same channel Fig 40, 2000 yards long to deliver 3000 cubic feet per minute would be

$$\frac{\left(\frac{3000}{62\ 5} + 6\ 534\right)^2 - 42\ 8) \times 2000 \times 31\ 2}{896400 \times 62\ 5} = 3\ 26, \text{or } 3\tfrac{1}{4} \text{ inches.}$$

Adding the head due to velocity at entry (51), the mean velocity is $\frac{3000}{62\ 5} = 48$, and the maximum $\frac{48}{84} = 57$ feet per minute, or ·95 foot per second, the head for which by Col C of Table 15 is about $\frac{1}{4}$ inch, the total head is therefore $3\frac{1}{4} + \frac{1}{4} = 3\frac{1}{2}$ inches

(67) Table 18 has been calculated by the following modification of Eytelwein s rule —

$$\frac{(V + 1089)^2 - 0118858}{8975} = R\ S$$

In which V = the mean velocity over the whole area in feet per second

R = the hydraulic radius in feet or $\frac{\text{area in square feet}}{\textit{border in feet}}$

S = the slope or $\frac{\text{fall in inches}}{\text{length in inches}}$

By this Table approximately correct results may be obtained with less labour than by the rules

1st. To find the Velocity —Multiply the area of the channel in square feet by the fall in inches, and divide the product by the border in feet multiplied by the length of the channel in inches find the nearest number thereto in Col B of Table 18, and oppo-

site to that number in Col A is the required velocity Thus for the case in (65) we have $\frac{62\ 5 \times 1}{31\ 2 \times (1760 \times 36)} = \cdot 0000316$, the nearest number to which is *00003043* opposite ·425 foot per second. By interpolation we may obtain a nearer approximation, for, as R S varies nearly as V^2, we have $\left(\frac{425^2 \times \cdot 0000316}{00003043}\right)^{\frac{1}{2}}$ or $\left(\frac{180625 \times \cdot 316}{\cdot 3043}\right)^{\frac{1}{2}} = \cdot 4331$ foot per second, hence the discharge comes out $4331 \times 60 \times 62 \cdot 5 =$ 1624 cubic feet per minute, or practically the same as by the rule (65)

TABLE 18 —For the DISCHARGE of CANALS, RIVERS, &c, by EYTELWEIN'S RULE

Mean Velocity in Feet per Second.	R. S.	Mean Velocity in Feet per Second.	R. S.
025	*0000006734*	*6*	*00005466*
05	000001489	65	00006284
075	00000244	7	00007158
1	000003538	75	00008087
125	000004771	8	00009072
15	000006144	85	00010112
175	000007656	9	0001121
2	000009307	95	0001236
225	0000111	1 0	0001357
25	00001303	1 1	00016146
275	00001510	1 2	0001895
3	00001730	1 3	00021984
325	00001966	1 4	0002524
35	00002214	1 5	00028703
375	00002477	1 6	00032402
4	00002753	1 7	0003632
425	00003013	*1 8*	*0004047*
45	000033184	1 9	000448
475	00003666	2 0	0004913
5	*[illegible]*	*2 5*	*[illegible]*
55	00004705	3 0	001075
A	**B**	**A**	**B**

2nd To find the [illegible] given discharge
given area, and by 60, the mean velocity

per second; find the nearest number to that in Col. A, which, multiplied by the border in feet and by the length of the channel in inches, and divided by the area in square feet will give the fall in inches. Thus, for the case in (66) we have $\frac{3000}{62 \cdot 5}$ = 48 feet per minute, or $\frac{48}{60}$ = ·8 foot per second, the tabular number for which is ·00009072, then

$$\frac{\cdot 00009072 \times 31 \cdot 2 \times (2000 \times 36)}{62 \cdot 5} = 3 \cdot 26 \text{ inches fall,}$$

as before.

68. "*Case of a Mill-stream.*"—As an example of the practical application of the rules, we will take a case in which it is desired to utilize a stream of water for driving a corn-mill. Say we have a stream 1500 yards long, with a total fall of 6 ft. 6 in. from the tail of the preceding mill. We have first to ascertain the quantity of water at disposal, selecting a spot where the current appears to be tolerably uniform for some 100 feet, and a season when the quantity is an average one according to local authorities, say we take it at a point 24 feet wide as in Fig. 11. We have then to obtain the area of the stream, and to do that, may divide the width into eight equal spaces of 3 feet each, as in the Figure, which may be done conveniently by stretching a tape across the stream; then we measure the depths midway between those divisions or at 1·5 foot, 4·5, 7·5 feet, &c., &c., using a measuring rod with a flat board about 7 or 8 inches square at the end of it, to prevent penetrating the soft bottom, and thus we obtain the series of measurements given in the figure, the mean of which we find to be 1·156 foot; the area is therefore 1·156 × 24 = 27·74 square feet. To find the velocity, two lines may be stretched across the stream near the surface, and say a "chain" or 66 feet apart, and a float being placed a few yards above the highest one, and in the centre of the width, or rather where the velocity is observed to be greatest, the exact time in passing from line to line is carefully noted. This float should be a small piece of *thin* wood, say only ½-inch thick, so

as to be almost wholly immersed, and thus expose little surface to the action of the wind Say that the float travels the 66 feet in 20 seconds, in one minute therefore it would be $\frac{66 \times 60}{20} =$ 198 feet This being the maximum velocity, the mean (50) over the whole area would be $198 \times 84 = 166$ feet per minute, hence the discharge is $166 \times 27\ 74 = 4600$ cubic feet per minute

(69) The total fall is 6 feet 6 inches, allowing 6 inches for the fall of the stream itself, the net fall at the wheel will be 6 feet, a cubic foot of water weighing 62 3 lbs, the horse-power being 33,000 foot pounds, and allowing that a breast-wheel yields 50 per cent, or 5 of the gross power of the water, we have $\frac{4600 \times 62\ 3 \times 6 \times\ 5}{33000} = 26$ horse power A pair of 4-feet stones, grinding 4 bushels of corn per hour, requires about 4 horse-power, and a dressing machine about 6 horse, if we allow four pairs of stones, we should require $16 + 6 = 22$ horse-power, leaving 4 horse-power for the mill gearing and small machines, &c The diameter of the water-wheel may be about 2 5 times the fall, say 15 feet, and the speed of its circumference being 4 feet per second, or 240 feet per minute, and the depth of the bucket 1 5 foot, the width of the wheel would be $\frac{4600}{240 \times 1\ 5} = 12\ 8$, say 13 feet With other kinds of water-wheel the duty would be different a good overshot wheel would give from 70 to 80 per cent, a breast-wheel from 45 to 60, and an undershot, in which the water acts only by its impulse, from 27 to 30 per cent

(70) The channel must now be altered, so as to deliver 4600 cubic feet per minute, with a fall of 6 inches in 1500 yards or $\frac{1760 \times 6}{1500} = 7$ inches per mile When altered to the form A, B, C, D, the area will be $\frac{24 + 12}{2} \times 3 = 54$ square feet, the mean velocity to discharge 4600 cubic feet will be $\frac{4600}{54} = 85\ 2$

feet per minute, the border is 6 7 + 12 + 6 7 = 25 1 feet, and the hydraulic radius $\frac{51}{25\ 1} = 2\ 126$ feet Then by Table 30 between 2 and 2 2 radii, the velocity 85 2 feet is found to be under the fall of 7 inches per mile, the fall we allowed It should be observed that it is imperative that the slope shall be *uniform* from end to end, at least where the area of the channel is uniform.

CHAPTER IV

ON WEIRS, OVERFLOW-PIPES, &c

(71) "*Weirs*"—Fig 36 shows a weir arranged for the purpose of gauging experimentally the quantity of water passing down the stream A is a plate of thin iron with a notch cut out of it wide enough by estimation to carry off the water with a moderate depth of overfall, this is screwed to a thick plank B, to obtain the requisite stiffness for the plate, and the whole is fixed in the stream as shown C is a stake with a flat and level top, which is driven into the bed of the stream to such a depth that its top is exactly level with the lip of the weir, and the depth of water flowing over is measured by a common rule held on its summit The proper distance of the stake from the weir depends on the quantity of water to be dealt with, in small weirs it may be from 1 to 2 feet, in very large ones 20 to 25 feet the object is to place it far enough away to avoid the curvature of surface which the water suffers as it approaches the weir, as shown by the Figure There is some uncertainty in measuring by a rule in the manner indicated, arising from the capillary attraction causing the water to adhere to the rule and to rise above its true height A more correct method is to use Francis's hook gauge, a rough modification of which is shown by Fig 36 The stake J is, in this case, driven to such a depth that its top is at a height convenient to the eye, say 30 inches above the level of the lip of the weir, then a rough hook gauge D, formed of

wood about 1 inch thick, is cut in the form shown, the end E being flat and level, and the length E F made exactly equal to G H or 30 inches The hook-gauge is held against the stake, and carefully adjusted, by the hook at E being first immersed, and then raised until it just coincides with the surface of the water, the depth of overflow is then given by the distance from the top of the stake to the top of the gauge at F, measured by a rule, &c

(72) With a thin plate, and depths thus measured from still water, we have the following rules —

$$G = d \times \sqrt{d} \times l \times 2\ 67$$

$$l = \frac{G}{d \times \sqrt{d} \times 2\ 67}$$

$$d = \left(\sqrt[3]{\frac{G}{l \times 2\ 67}}\right)^2$$

In which G = gallons discharged per minute
„ d = depth of overflow in inches.
„ l = length of weir in inches

Thus, with 2 inches overflow, a weir 72 inches long discharges $2 \times 1\ 4142 \times 72 \times 2\ 67 = 513\ 7$ gallons per minute, again, *to discharge 691 gallons per minute, with 3 inches overflow*, we should require a length of $\frac{691}{3 \times 1\ 732 \times 2\ 67} = 50$ inches, and again, to find the depth of overflow to carry 1282 gallons, with a length of 60 inches we have $\frac{1282}{60 \times 2\ 67} = 8$, then $\sqrt[3]{8} = 2$, and $2^2 = 4$ inches, the depth required Table 19 has been calculated by these rules, and its use may be illustrated by the examples just given, thus with 2 inches overflow the Table gives 7 552 gallons per inch, and a weir 72 inches wide will discharge $7\ 552 \times 72 = 513\ 7$ gallons, a weir with 3 inches overflow discharges 13 87 gallons per inch of width, and for 691 gallons we require a length of $\frac{691}{13\ 87} = 50$ inches, a weir 60 inches

long discharging 1282 gallons is equal to $\frac{1282}{60} = 21 \cdot 36$ gallons per inch wide, which by the Table is due to 4 inches overflow, &c.

TABLE 19 —Of the DISCHARGE of WATER over WEIRS, 1 inch wide, in GALLONS per MINUTE

Depth.	Gallons.	Depth.	Gallons.	Depth.	Gallons	Depth.	Gallons.	Depth	Gallons.
inch.		inch.		inch		inch.		inch.	
¼	3338	5	29 85	16½	179 0	52	1001	89	2242
⅜	6132	5⅛	30 97	17	187 1	53	1030	90	2280
½	914	5¼	32 12	17½	195 5	54	1060	91	2318
⅝	1 3[illegible]9	5⅜	33 26	18	203 9	55	1089	92	2356
¾	1 734	5½	34 44	19	221 1	56	1119	93	2395
⅞	2 185	5⅝	35 62	20	238 8	57	1149	94	2433
1	2 670	5¾	36 85	21	256 0	58	1179	95	2472
1⅛	3 185	5⅞	38 02	22	275 5	59	1210	96	2512
1¼	3 818	6	39 21	23	294 4	60	1241	97	2551
1⅜	4 305	6¼	41 72	24	313 9	61	1272	98	2590
1½	4 905	6½	44 25	25	333 8	62	1304	99	2630
1⅝	5 531	6¾	46 82	26	354 0	63	1335	100	2670
1¾	6 167	7	49 45	27	374 6	64	1367	101	2711
1⅞	6 855	7¼	52 12	28	395 0	65	1399	102	2751
2	7 552	7½	54 84	29	417 0	66	1432	103	2791
2⅛	8 271	7¾	57 61	30	438 7	67	1464	104	2825
2¼	9 011	8	60 41	31	460 8	68	1497	105	2873
2⅜	9 773	8¼	62 54	32	483 3	69	1531	106	2914
2½	10 55	8½	66 17	33	506 1	70	1564	107	2955
2⅝	11 36	8¾	69 11	34	529 3	71	1597	108	2997
2¾	12 18	9	72 09	35	552 8	72	1631	109	3039
2⅞	13 02	9¼	75 12	36	576 7	73	1665	110	3080
3	13 87	9½	78 18	37	600 9	74	1700	111	3122
3⅛	14 75	9¾	81 29	38	625 4	75	1734	112	3165
3¼	15 61	10	84 43	39	650 4	76	1769	113	3207
3⅜	16 55	10½	90 84	40	675 5	77	1804	114	3250
3½	17 48	11	97 41	41	700 [illegible]	78	1839	115	3[illegible]93
3⅝	18 42	11½	104 1	42	726 7	79	1875	116	3336
3¾	19 39	12	111 0	43	752 9	80	1910	117	[illegible]379
3⅞	20 37	12½	118 0	44	779 3	81	1946	118	[illegible]422
4	21 36	13	125 1	45	806 0	82	1983	119	3466
4⅛	22 37	13½	132 5	46	832 8	83	2019	120	3510
4¼	23 39	14	13[illegible] 6	47	860 3	84	[illegible]	121	[illegible]53
4⅜	24 38	14½	147 4	48	887 9	85	20[illegible]3	122	[illegible]
4½	25 40	15	1[illegible]5 1	49	915 8	86	2130	123	[illegible]12
4⅝	26 56	15½	163 0	50	[illegible]44 0	87	2162	124	[illegible]57
4¾	27 [illegible]	16	170 9	51	972 4	88	2[illegible]01	125	[illegible]31
4⅞	28 74								

(73) "*Effect of Thickness of Crest*"—When the lip of the weir has a considerable thickness, which is frequently a practical necessity, the discharge will be less than with a thin plate, a loss arising from friction. Mr Blackwell's experiments, made on a large scale, and with depths of overfall ranging from 1 inch to 14 inches, give us the following coefficients, by which Table 19 may be adapted to the forms commonly met with in practice —

	Ratio of Discharge
Thin plate, weir 10 feet long	1 000
P	815
C	712
	760

Thus, say we have a river-weir 30 feet wide, with 6½ inches overfall, the crest having a slope of 1 in 12, then the discharge will be 44 25 × 360 × 76 = 12,107 gallons per minute, or $\frac{12107}{6\ 23}$ = 1943 cubic feet

(74) Table 19 may be applied to rectangular apertures like Fig 85, for the discharge in such a case is the *difference* between two weirs, A, B, C, D, and A, E, F, D, say the head to the top of the aperture (A, B) is 16½ inches, and to the bottom (A, E) 22 inches, and that the width (E, F) is 20 inches Then, by Table 19, 22 inches = 275 5 gallons per inch, and 16½ inches = 179 0 gallons, the difference is, therefore, 275 5 − 179 0 = 96 5, and the discharge 96 5 × 20 = 1930 gallons, but as *contraction* occurs on four sides in this case, see (51), the real discharge would be 1930 × 635 — 667 = 1837 gallons per minute The coefficients in (73) do not apply to apertures with large heads

Similarly we may determine the discharge of round apertures, or approximately of any regular figures, which will not differ materially from that of a circumscribing rectangular opening, reduction being made for the true area of the figure whose discharge is required Thus, say we require the discharge of a

circular aperture 12 inches diameter, the head measured from the upper edge of the orifice being 14 inches, therefore, 26 inches above the lower edge Here we have 351 0 − 139 8 = 214 2 gallons per inch wide, and if the aperture were rectangular it would discharge 214·2 × 12 = 2570 4 gallons, but being circular its area is ·7854, that of a circumscribing rectangle being 1 0, and the true discharge is 2570 4 × 7854 × 635 — 667 = 1922 gallons per minute

(75) "*Effect of Velocity of Approach to Weirs, &c*"—We have so far supposed that the head has been measured from still water, or that the channel was of very large area in proportion to the discharging orifices. When the channel is of small area, the water will have a sensible velocity as it approaches the aperture, which will increase the discharge, and correction must be made for it by adding to the measured head, that due to the observed velocity of approach. Table 15 gives the head due to a range of velocities such as are likely to be met with in ordinary practice, thus, in the case of a weir 60 inches wide, with $3\frac{3}{8}$ inches overfall, the discharge = 18 42 × 60 = 1105 2 gallons, but if the velocity of approach had been 66 feet per minute or 1 1 foot per second, we find the head due to that velocity in Col B = $\frac{1}{4}$ inch, and the head on the weir becomes $3\frac{3}{8} + \frac{1}{4} = 3\frac{5}{8}$, and the discharge 20 37 × 60 = 1222 gallons More strictly, it is the *difference* between two weirs with the respective overfalls of $\frac{1}{4}$ inch and $3\frac{5}{8}$, or (20 37 − 3338) × 60 = 1202 gallons, instead of 1105 2 gallons, as we found it for still water

(76) "*Correction for Short Weirs* —The rules in (72) assume that the discharge of a weir is simply proportional to its length This is not strictly correct, in ordinary cases where the weir is narrower than the channel the issuing stream suffers *contraction* at the two ends, by which its length is virtually reduced, and as this contraction is about the same with all lengths its effect is proportionally greater with short weirs than with long ones The experiments of Francis show that the effect of contraction at both ends is to reduce the effective length 0 2 inch for each inch in depth of overfall, or 1 inch with 5 inches deep, 2 inches with 10 inches deep, &c With 5 inches overfall, and weirs

TABLE 20.—The DISCHARGE of OVERFLOW PIPES for TANKS, &c.

Depth of Overflow in Inches.	Diameter of the Trumpet mouth in Inches													
	2	3	4	5	6	7	8	9	10	11	12	14	16	18
	Gallons Discharged per Minute.													
¼	6	9	12	15	18	21	24	27	30	33	36	40	47	53
½	11	16	22	27	32	38	43	48	54	59	65	75	86	97
1	17	25	31	42	50	59	67	75	84	92	100	118	134	151
1¼	23	35	47	57	70	82	94	106	117	129	140	164	188	211
1½	31	46	62	77	92	108	123	139	154	170	185	216	247	278
1¾	39	58	78	97	116	136	155	175	194	214	233	272	311	350
2	47	71	95	119	142	166	190	214	237	261	285	332	380	427
2¼	..	85	113	142	170	198	227	255	283	312	340	397	453	510
2½	..	100	133	166	199	232	265	299	332	365	398	465	531	597
2¾	..	116	155	194	233	271	310	349	388	427	465	543	621	698
3	..	131	174	218	262	305	349	392	436	480	523	611	698	785
3¼	..	..	197	246	295	344	394	443	492	541	590	689	787	886
3½	..	..	220	275	330	385	440	495	550	605	660	770	880	990
3¾	..	..	244	305	366	427	488	549	610	671	732	854	897	1098
4	..	..	..	336	403	470	537	605	672	740	806	941	1075	1210

5, 10, 20, 50, and 100 inches long, Table 19 gives 149, 298, 597, 1492, and 2985 gallons per minute, but deducting one inch from all those lengths, they are reduced to 4, 9, 19, 49, and 99 inches, and the discharges become 119, 268, 567, 1462, and 2955 gallons. Francis gives a rule for weirs with thin plates, of which the following is a modification —

$$G = 2\ 4953 \times (l - 0\ 1\, n\, d) \times d^{\frac{3}{2}}$$

In which n = the number of end contractions (usually two), and the rest as in (72) Where the weir is the full width of the channel, $n = 0$ By this rule, with the real lengths given above, the discharges come out 112, 251, 530, 1367, and 2762 gallons, which are rather less than with the *reduced* lengths by Table 19

(77) "*Overflow-pipes to Tanks, &c*"—The rules and Table for weirs apply also with approximate correctness to an overflow-pipe to a tank, as in Fig 46, which may be considered as a circular weir whose length is equal to the circumference of the *trumpet-mouth* The following rules will give the same result more directly —

$$G = D \times \sqrt{D} \times d \times 8\ 4$$

$$d = \frac{G}{8\ 4 \times D \times \sqrt{D}}$$

$$D = \left(\sqrt[3]{\frac{G}{8\ 4 \times d}}\right)^2,$$

In which d = the diameter of the trumpet mouth in inches, D = depth of water over the lip (measured from still-water) in inches, and G = gallons discharged per minute Table 20 has been calculated by this rule The size of the discharge pipe A must be determined by the ordinary rules, with short pipes the discharge is governed principally by the head due to velocity, which is given by Table 1 rather than Table 2 for a pipe of this form For tanks 3 feet deep, and with a discharge-pipe of that length, Table 21 gives the maximum discharge Say we had to provide for 400 gallons per minute —Table 21 shows that

4 inches is the smallest size of pipe admissible, and allowing $2\frac{1}{2}$ inches for overflow, Table 20 gives 12 inches for the least diameter of trumpet-mouth. We must allow some margin for contingencies, and in such a case, the lip of the trumpet-mouth should not be less than 3 inches below the top of the tank, and thus 3 inches is practically lost in the useful depth of the tank.

TABLE 21.—OF THE MAXIMUM DISCHARGE OF VERTICAL PIPES 3 FEET LONG.

Diameter of Pipe in Inches.	Maximum Discharge in Gallons per Minute.	Diameter of Pipe in Inches.	Maximum Discharge in Gallons per Minute.
1	19	$3\frac{1}{2}$	303
$1\frac{1}{2}$	45	4	400
2	88	5	630
$2\frac{1}{2}$	145	6	920
3	220	7	1300

(78.) Fig. 47 shows a simple contrivance of the late Mr. Appold, by which this loss may be avoided, and the water-level not allowed to rise more than about $\frac{1}{4}$th of an inch above the lip of the trumpet-mouth, even when the descending pipe is discharging full-bore. B is a dished cover of sheet copper, &c., supported on four brackets C, C, cast on the pipe, so that its lip at D is at the same level as the lip of the trumpet-mouth. When the water rises to that level, it does not immediately flow over when the lip is dry, but rises perhaps $\frac{1}{16}$th of an inch above it, and then, suddenly overflowing, creates a partial vacuum under the cover, causing the water to rise there above the level of the wa[illegible] in the tank and filling the pipe full-bore. The air under cover is swallowed up by the rush of the water, and the maxin[illegible] *quantity which the pipe can carry is delivered.* This contin[illegible] till, the water being drawn down below the lip of the cover a[illegible] air enters, and the [illegible] denly ceases, to be again repe[illegible] should the water r[illegible] ction depends on the suctio[illegible] the down-pipe, whic[illegible] erfect if the bore is not [illegible] filled, it is expedient [illegible] at pipe *much* larger t[illegible]

necessary It is usual to construct the pipe so as to serve as a wash-out valve, the joint at the bottom being turned and bored to fit water-tight.

(79) "*Overflows to Fountains*"—In ornamental fountains with shallow basins it is important that the water-level should fluctuate as little as possible, hence the form of overflow-pipe just described is specially applicable to such cases It is generally desirable that the pipe should be concealed, which may be done by fixing it in a small supplementary cistern by the side of the fountain basin, with a large passage between them For small fountains with say 100 gallons per minute, an inverted overflow-pipe may be used, as in Fig 42, a short pipe A, which serves also as a waste-pipe to empty the basin when necessary by the cock B, carries the overflow trumpet-mouth C Say we have 100 gallons, then with a 6 inch pipe at A, the head for velocity at entry would be about 1 inch, and with a 12 inch trumpet mouth the head for overflow, by Table 20, is also 1 inch, so that the water-line would fluctuate 2 inches The cock B may be of smaller size, say 3 inches, the end of the pipe being reduced to suit it With care, such an arrangement might be used for a very large quantity, by adjusting the cock so as to carry rather less than the supply, leaving the trumpet mouth to carry off the surplus and regulate the level

(80) "*Common Overflow-pipe*"—When an overflow takes the form of a short pipe inserted in the side of a cistern as in Fig 45, and the water to be carried off is just sufficient to fill the pipe, the discharge will be given approximately by the following rule —

$$G = d^{2.5} \times 3.2,$$

In which G = gallons discharged per minute
„ d = diameter in inches

Table 22, which has been calculated by this rule, may also be useful for another purpose It sometimes happens that the only datum which an engineer obtains as a basis for rough estimates is, that a spring or stream delivers "about as much as a pipe of a certain size would carry This, of course, is very indefinite, but in most cases it means the amount which a pipe would dis-

charge without extra pressure, as in Fig 45 and Table 22: thus an 8-inch pipe just filled delivers about 580 gallons per minute: —*the pipe in (37) was observed to be nearly filled with the issuing stream when discharging 561 gallons.*

TABLE 22.—*Of the* DISCHARGE *of* OUTLET-PIPES, Fig 45

Diameter Inches.	Gallons per Minute.	Diameter, Inches.	Gallons per Minut	Diameter Inches.	Gallons per Minute
1	3.2	5	179	13	1950
1½	8.8	6	283	14	2416
2	18.1	7	415	15	2788
2½	31.6	8	580	16	3277
3	50.0	9	778	17	3814
3½	73.3	10	1012	18	4400
4	112.4	11	1281	19	5037
4½	138.0	12	1600	20	5725

CHAPTER V.

ON THE STRENGTH OF WATER-PIPES — RAINFALL, &c., &c.

(81) "*Strength of Thick Pipes*"—The strength of pipes to resist an internal pressure is not simply proportional to the thickness of metal The material stretches or extends under a tensile strain, and the result of extension is, that the inside metal is more strained than that of the outside, and that thick pipes are weaker in proportion to their thickness than thin ones Barlow has given the following rules :—

$$T = \frac{R \times P}{b - P}$$

$$P = \frac{S \times T}{R + T}$$

$$S = \frac{(R + T) \times P}{T};$$

In which S = the cohesive strength of the metal per square inch

„ P = the internal pressure per square inch, in the same terms as S

„ R = the radius of the inside of the pipe in inches

„ T = the thickness of metal in inches

For cast-iron S may be taken at 7.142 tons, or 16,000 lbs. per square inch, and with that strength we obtain the bursting pressure given by Table 23, which shows that with a 10 inch pipe a thickness of 10 inches gives only four times the strength due to a thickness of 1 inch.

TABLE 23.—Of the STRENGTH of a 10-INCH CAST IRON PIPE to RESIST INTERNAL PRESSURE, in Tons per Square Inch

Thickness in inches	1	2	3	4	5
Pressure by Barlow's rule	1.19	2.04	2.68	3.17	3.57
Pressure by exact calculation	1.226	2.161	2.896	3.485	3.972
Thickness in inches	6	7	8	9	10
Pressure by Barlow's rule	3.90	4.17	4.40	4.59	4.76
Pressure by exact calculation	4.337	4.722	5.019	5.275	5.5

Barlow's rule supposes that the extensions are simply proportional to the strain, which is not quite correct; by taking the true extensions we obtain the *second series* of bursting pressures given in the Table by a calculation which need not be here elaborated.

(82.) *Strength of Thin Pipes.*—Barlow's rule is quite inapplicable to comparatively thin pipes, such as are commonly used for water and gas; there are other and practical considerations which that rule does not contemplate. With thin pipes and moderate pressures, we have to consider not only the thickness necessary to bear the pressure, but also that required to bear the traffic along the roads in which they are ordinarily laid. Again, although great care is taken to keep the core central it is seldom perfectly so; a pipe intended to be ½ inch thick is frequently

TABLE 24.—Of the THICKNESS and WEIGHT of CAST-IRON SOCKET-PIPE to BEAR SAFELY DIFFERENT PRESSURES of WATER

Diameter in Inches	Length exclusive of Socket.		For Gas &c.				100 feet.				250 feet.				500 feet.				750 feet.				1000 feet.			
	ft.	in.	thick.	cwt.	qrs.	lbs.	thick.	cwt.	qrs	lbs	thick	cwt.	qrs	lbs	thick.	cwt.	qrs	lbs	thick	cwt	qrs	lbs	thick.	cwt	qrs	lbs
1½	6	0	27	0	1	3	28	0	1	4	29	0	1	5	30	0	1	7	31	0	1	8	33	0	1	10
2	6	0	29	0	1	17	30	0	1	19	31	0	1	20	33	0	1	23	35	0	1	26	37	0	2	2
2½	6	0	30	0	2	1	31	0	2	3	33	0	2	7	35	0	2	11	37	0	2	14	40	0	2	20
3	9	0	32	0	3	18	33	0	3	21	35	1	0	3	38	1	0	9	41	1	0	19	44	1	1	0
4	9	0	35	1	1	7	37	1	1	15	39	1	1	24	43	1	2	13	47	1	3	1	51	1	3	18
5	9	0	37	1	2	23	39	1	3	5	42	1	3	21	47	2	0	19	52	2	1	16	57	2	2	14
6	9	0	39	2	0	16	42	2	1	6	45	2	1	25	51	2	3	6	57	3	0	15	63	3	1	24
7	9	0	41	2	2	13	44	2	3	8	48	3	0	9	55	3	2	4	62	4	0	0	69	4	1	21
8	9	0	43	3	0	14	46	3	1	10	51	3	2	23	59	4	1	4	67	4	3	13	75	5	1	22
9	9	0	45	3	2	18	48	3	3	17	53	4	1	7	63	5	0	14	72	5	3	12	81	6	2	10
10	9	0	47	4	0	26	51	4	2	10	57	5	0	15	67	6	0	4	77	6	3	21	87	7	3	9
12	9	0	49	5	1	2	54	5	3	6	61	6	2	6	73	7	3	11	85	9	0	15	97	10	2	0
15	9	0	53	7	1	0	59	8	0	6	68	9	1	4	83	11	1	9	98	13	1	14	1 13	15	2	0
18	9	0	57	9	1	0	64	10	1	16	75	12	1	0	93	15	0	11	1 11	18	0	0	1 29	21	0	0
21	9	0	60	11	0	11	69	12	3	12	81	15	0	18	1 02	19	1	7	1 23	23	1	0	1 44	27	0	10
24	9	0	64	13	2	0	73	15	2	9	88	18	3	2	1 12	23	2	4	1 36	28	2	9	1 60	33	2	14
30	9	0	69	18	0	14	81	21	1	3	1 00	26	1	2	1 29	31	3	4	1 59	42	2	18	1 89	50	2	5
36	9	0	75	23	2	16	89	28	0	6	1 11	35	0	0	1 47	46	1	10	1 83	57	3	0	2 19	60	1	12

$\frac{3}{8}$ths at one side and $\frac{5}{8}$ths at the other, and of course the least thickness governs the strength of the pipe And again, there are in most cases shocks arising from the closing of cocks, &c, against which it is necessary to provide adequate strength In thin pipes, therefore, the determination of the thickness becomes a practical question, and we must obtain an empirical rule from experience The rule may take the following form —

$$t = \left(\frac{\sqrt{D}}{10} + 15\right) + \left(\frac{H \times D}{25000}\right),$$

In which D = the diameter of the pipe in inches.
„ H = the safe head of water, in feet
„ t = the thickness of metal in inches

Table 24 has been calculated by this rule, and we have also given the approximate weights from gas pipes in which the pressure is practically nothing, up to 1000 feet of water Engineers usually specify the *weight* of their pipes rather than the thickness, leaving the founder to fix that for himself which long practice enables him to do with considerable precision. Of course absolute correctness cannot be attained, and should not be expected, a margin should be allowed, say one pound to the inch, either way, so that, for instance, a 10-inch pipe for 100 feet head, specified to weigh 4 cwt 2 qrs 10 lbs, as per Table 24, should not be rejected if its real weight is between 4 cwt 2 qrs 0 lbs and 4 cwt 2 qrs 20 lbs. &c Founders consider this to be a fair allowance for variation in weight

(83) "*Proportions of Socket pipes*"—The joints of water-pipes are usually made by sockets and spigots run with melted lead, and this is the best mode. Such pipes are easy to cast, and consequently cheap, the joints are more easily made than with flanges, and they admit a considerable departure from the strictly straight line which is sometimes very convenient But to allow for this the sockets must be made of larger diameter than is necessary where the line is straight, and for this reason, perhaps, sockets are frequently made larger than they should be for making a good joint For ordinary cases $\frac{1}{4}$ inch in thickness or $\frac{1}{2}$ inch in diameter will suffice for pipes of 3 inches diameter

TABLE 27 —Of the PROPORTIONS of CAST IRON FLANGE PIPES

Diameter of Pipe	Diameter of Flange.	Thickness of Flange	No of Bolts	Diameter of Bolts	Diameter of Circle of Bolts
inches	inches.	inches.		inches	inches
1½	4½		3	⅜	3¼
2	5¼	½	3	7/16	3¾
2½	6	9/16	4	7/16	4½
3	6½	⅝	4	½	5
4	8	⅝	4	9/16	6¼
5	9¼	¾	4	9/16	7¼
6	10½	¾	6	9/16	8¾
7	12	¾	6	⅝	10
8	13¼	⅞	6	⅝	11¼
9	14½	⅞	6	⅝	12¼
10	16	1	6	¾	13½
12	18¼	1	6	¾	16

(85) "*Strength of Lead Pipes*"—The strength of lead pipe may be calculated by Barlow's rule (81), taking the cohesive strength of drawn lead at 2745 lbs per square inch, as determined by direct experiment. Lead pipes are made of various weights to suit the varying requirements of practice, taking medium weights, and deducing the thickness therefrom, we obtain the following Table, in which the safe working pressure is taken at $\frac{1}{10}$th of the bursting strain —

Diameter of pipe	½	⅝	¾	1	1¼	1½	1¾	2
Weight of pipe lbs per foot	1 33	1 47	1 67	2 80	4 33	6 0	6 75	8 0
Safe pressure feet of water	232	183	174	151	152	140	122	116

(86) "*Power of Horses, &c, in raising Water*"—The power of men, horses, &c, in raising water varies with the duration of the labour The following Table gives the number of gallons raised 1 foot high per minute, with common deep-well pumps, and the mean velocity in feet per minute

Velocity	Hours per Day	4	5	6	8	10
176	Horse walking in a circle	1653	1480	1350	1169	1040
180	Pony or mule, ditto	1102	986	898	780	697
120	Bullock, ditto	1470	1314	1200	1040	930
157	Ass, *ditto*	457	410	374	323	290
220	Man, with winch pump	249	222	203	176	157
147	*Ditto Contractor's pump*	205	183	167	145	130

A good high pressure steam-engine should raise 3300 gallons 1 foot high per minute per nominal horse-power, the friction of the pumps being compensated by the excess of the indicated power over the nominal

(87) "*Rainfall*"—The depth of rain in this country varies very much with the locality, the east coast is the driest, the annual rainfall being in Northumberland about 28 67 inches, diminishing thence gradually to 23 in Norfolk and to 19 8 in Essex, which is the minimum Thence southward and westward it gradually increases to 25 6 in Kent, 30 61 in Sussex, 38 75 in Dorset, 48 3 in Devon, and 50 6 in Cornwall The midland districts have a medium fall Middlesex 21 1, Leicester 26 0, Hereford 29 27, Cheshire 31 3, &c, &c

"*Heavy Rains*"—For town drainage and other purposes, we require to know the maximum fall of rain during storms We find that in

1	5	15	30	45	60	120	180 minutes

the maximum fall of rain may be

0 2	0 75	1 0	1 8	2 5	3 25	3 6	4 inches,

which is at the rate per hour of

12	9	4	3 6	3 3	3 25	1 8	1 33 inches

"*Rain-water Tanks*"—Where it is desired to utilize as much as possible of the rain falling on a building the minimum size of tank becomes an important but complicated question Taking a place with 24 inches annual rainfall we have evidently an allowance for a regular consumption of 2 inches per month But there may be a drought in which for one month no rain falls, and the tank must have 2 inches in store to supply the deficiency There may also be a wet month with 6 inches of rain, and as only 2 inches is consumed, 4 inches must be stored The tank must therefore hold $2 + 4 = 6$ inches or $\frac{1}{4}$th of the annual rainfall Again, for two months we require 4 inches but the rainfall varies from $1\frac{1}{2}$ to $7\frac{1}{2}$ inches, and the tank must hold $(4 - 1\frac{1}{2}) + (7\frac{1}{2} - 4) = 6$ inches as before For three months we require 6 inches, but the rainfall varying from 2 4 to 8 7 inches, the tank should hold $(6 - 2\ 4) + (8\ 7 - 6) =$

6 3 inches. From all this we find that a rain water tank should hold at least $\frac{1}{4}$th of the annual rainfall Thus, with 24 inches, or 2 feet per year a building 1830 square feet in area, collects $1830 \times 2 = 3660$ cubic feet, allowing a consumption of 10 cubic feet or 62 3 gallons per day, and the tank should hold $3660 - 4 = 915$ cubic feet

(88) "*Weight and Pressure of Water*"—A gallon of water at 62° weighs 10 lbs, and contains 277 274 cubic inches, or 16046 cubic foot hence a cubic foot weighs 62 321 lbs, and contains 6 2321, or nearly $6\frac{1}{4}$ gallons Table 28 gives the pressure in pounds per square inch due to given columns of water and mercury

TABLE 28 —OF EQUIVALENT PRESSURES in POUNDS per SQUARE INCH FEET of WATER, and INCHES of MERCURY at a Temperature of 62° Fahr

Pounds per Square Inch	Feet of Water	Inches of Mercury	Pounds per Square Inch	Feet of Water	Inches of Mercury
1	2 311	2 046	2 5962	6	5 31198
2	4 672	4 092	3 0289	7	6 19731
3	6 933	6 138	3 4616	8	7 08764
4	9 244	8 184	3 8942	9	7 96,97
5	11 555	10 230	48575	1 12952	1
6	13 866	12 276	97750	2 25904	2
7	16 177	14 372	1 46675	3 38856	3
8	18 488	16 368	1 95500	4 51808	4
9	20 800	18 414	2 44375	5 64 60	5
4377	1	88533	2 93250	6 77712	6
8654	2	1 77066	3 42125	7 90664	7
1 2981	3	2 65599	3 91000	9 03616	8
1 7308	4	3 54132	4 39875	10 16568	9
2 1635	5	4 47665			

EXAMPLE —Required the Pressure per Square Inch and Equivalent Column of Mercury for a Head of 247 feet of Water

Feet of Water		Pounds per Square Inch.		Inches of Mercury
200	=	86 54	or	177 066
40	=	17 308		35 413
7	=	3 079		6 197
247	=	106 877	"	218 676

LONDON PRINTED BY WILLIAM CLOWES AND SO S LIMITED STAMFORD STREET
AND CHARING CRO S

GE IN OPEN CANALS, RIVERS, &C, WITH DIFFERENT HEADS

							FALL IN "FEET" PER MILE.
2	3	4	5	6	7	8	9
01364	02015	02727	03109	01091	01773	05451	06136

HOLE CROSS-SECTIONAL AREA IN FEET PER MINUTE.

31 5	42 3	48 8	51 6	59 8	61 6	69 1	73 2
48 8	59 8	69 1	77 2	81 6	91 4	97 7	103
59 8	73 2	81 6	91 6	101	112	120	127
69 1	81 6	97 7	109	120	129	138	146
77 2	91 6	109	122	131	144	151	161
81 6	103 6	120	134	147	158	169	179
91 4	111 9	129	144	158	171	183	194
97 7	119 6	138	154	169	183	195	207
103 6	126 9	146	164	179	194	207	220
109 2	133 7	154	173	189	201	218	232
114 5	140 3	162	181	198	214	229	243
119 6	146 5	169	189	207	224	239	254
124 5	152 5	176	197	216	233	249	264
129 2	158 3	183	204	224	242	258	274
133 8	163 8	189	211	232	250	267	284
138 1	169 2	195	218	239	258	276	293
142 4	174 4	201	225	247	266	285	302
146 5	179 4	207	232	254	274	293	311
150 5	184 4	213	238	261	282	301	319
154 4	189 1	218	244	267	289	309	328
162 0	198 4	229	256	281	303	324	344
169 2	207 2	239	267	293	316	338	359
176 1	215 6	249	278	305	329	352	374
182 7	223 8	258	289	317	342	365	388
189 2	231 7	267	299	328	354	378	401
195 4	239 3	276	309	338	365	391	414
201 4	246 6	285	318	349	377	403	427
207 3	253 8	293	328	359	388	414	440
212 8	260 7	301	337	369	398	425	452
218 2	267 5	309	345	378	409	436	463
229 0	280 5	324	362	397	429	458	486
239 2	293 2	338	378	414	448	478	508
249 0	305 2	352	394	431	466	498	528
258 4	316 6	365	409	448	483	517	548
267 6	327 6	378	423	463	500	535	567
288 8	353 9	408	457	500	540	577	611
308 8	378 3	436	488	535	578	618	655
327 6	401 3	463	518	567	613	655	695
345 4	422 9	488	546	598	646	691	733

TABLE 30.—OF THE VELOCITIES OF D

N INCHES PER MILE AND PER YARD

6	7	8	9	10	11	12	15	1[illegible]
00341	00398	00454	00511	00568	00625	00682	00852	010
MEAN VELOCITY THROUGHOUT THE								
17 3	18 6	19 9	21 1	22 3	23 4	24 4	27 3	29
24 4	26 4	28 2	29 9	31 5	33 1	34 5	38 6	42
29 9	32 3	34 5	36 6	38 6	40 5	42 3	47 3	51
34 5	37 3	39 9	42 3	44 6	46 8	48 8	54 6	59
38 6	41 7	44 6	47 3	49 8	52 3	54 6	61 0	66
42 3	45 7	48 8	51 8	54 6	57 3	59 8	66 9	73
45 7	49 4	52 8	55 9	59 0	61 9	64 6	72 1	79
48 8	52 8	56 4	59 8	63 1	66 1	69 1	77 1	84
51 8	56 0	59 8	63 4	66 9	70 1	73 3	81 9	89
54 6	59 0	63 0	66 9	70 5	73 9	77 2	86 4	94
57 3	61 9	66 1	70 1	73 9	77 5	81 0	90 6	99
59 8	64 6	69 1	73 3	77 2	81 0	84 6	94 5	103
62 3	67 3	71 9	76 3	80 4	84 3	88 1	98 4	107
64 6	69 8	74 6	79 1	83 4	87 5	91 4	102 1	111
66 9	72 2	77 2	81 9	86 3	90 6	94 6	105 7	115
69 1	74 6	79 8	84 6	89 2	93 5	97 7	109 2	119
71 2	76 9	82 2	87 2	91 9	96 4	100 7	112 5	123
73 3	79 1	84 6	89 7	94 6	99 2	103 6	115 9	126
75 3	81 3	86 9	92 2	97 2	101 9	106 4	119 0	130
77 2	83 4	89 2	94 6	99 7	104 5	109 2	122 1	133
81 0	87 5	93 5	99 2	104 6	109 8	114 5	128 0	140
84 6	91 4	97 7	103 6	109 2	114 6	119 6	133 7	146
88 1	95 1	101 7	107 8	113 6	119 2	124 5	139 2	15[illegible]
91 4	98 7	105 5	111 9	118 0	123 7	129 2	144 4	15[illegible]
94 6	102 2	109 2	115 8	122 1	128 1	133 7	149 5	163
97 7	105 4	112 8	119 6	126 0	132 2	138 1	154 4	16[illegible]
100 7	108 7	116 2	123 3	130 0	136 3	142 4	159 2	17[illegible]
103 6	111 9	119 6	126 9	133 8	110 2	146 5	163 8	17[illegible]
106 3	115 0	122 9	130 4	137 4	144 0	150 5	168 3	184
109 1	117 9	126 1	133 7	111 0	147 [illegible]	154 5	172 7	18[illegible]
114 5	123 7	132 3	110 3	147 9	1[illegible]3 0	162 0	181 1	19[illegible]
119 6	129 2	138 1	116 5	154 4	161 9	169 2	189 1	20[illegible]
124 5	134 5	143 8	152 5	160 7	168 [illegible]	17[illegible] 1	1[illegible] 9	[illegible]
129 2	139 5	149 2	158 3	166 8	17[illegible] 0	182 7	[illegible]01 3	2[illegible]
133 8	144 1	154 5	163 8	172 7	181 1	[illegible]9 2	211 5	[illegible]31
144 4	156 0	166 8	176 9	186 5	195 5	203 8	[illegible]	[illegible]
151 4	166 8	178 3	189 1	199 3	209 1	[illegible]	211 2	[illegible]
163 8	177 0	189 2	200 6	211 5	221 8	[illegible]31 6	[illegible]9 0	[illegible]
172 7	186 5	199 4	211 5	2[illegible]2 0	233 8	211 2	[illegible]3 0	[illegible]

—Of the Discharge of Pipes by Prony's Formula.

Diameter of the pipe in inches.						
5	6	7	8	9	10	12
Gallons discharged per minute.						
1·278	1 841	2 504	3 272	4 142	5 113	7 3
2 556	3 682	5 008	6 544	8 284	10 23	14 7
3 834	5 523	7 512	9 816	12 43	15 34	22 0
5 113	7 363	10 02	13 09	16 57	20 45	29 4
6 390	9 205	12 52	16 36	20 71	25 57	36 8
7 668	11 05	15 02	19 63	24 85	30 67	44 1
8 947	12 89	17 53	22 95	28 99	35 79	51 5
10 23	14 73	20 03	26 18	33 13	40 91	58 9
11 50	16 57	22 54	29 45	37 28	46 02	66 2
12 78	18 41	25 04	32 72	41 42	51 13	73 6
14 06	20 25	27 54	36 00	45 56	56 25	80 9
15 34	22 09	30 05	39 27	49 70	61 36	88 3
16 62	23 93	32 55	42 54	53 84	66 46	95 7
17 89	25 77	35 06	45 81	57 98	71 59	103 1
19 17	27 61	37 56	49 08	62 13	76 69	110 4
20 45	29 45	40 06	52 36	66 27	81 81	117 8
21 73	31 29	42 57	55 63	70 41	86 94	125 2
23 01	33 13	45 07	58 90	74 55	92 03	132 5
24 29	34 97	47 58	62 17	78 70	97 14	139 8
25 57	36 82	50 08	65 45	82 83	102 3	147 2
28 12	40 50	55 09	72 00	91 12	112 5	162 0
30 68	44 18	60 10	78 54	99 40	122 7	176 7
33 23	47 86	65 10	85 08	107 7	132 9	191 4
35 79	51 54	70 11	91 63	116 0	143 2	206 1
38 34	55 23	75 12	98 16	124 3	153 4	220 9
40 90	58 90	80 13	104 7	132 5	163 6	235 6
43 46	62 59	85 14	111 3	140 8	173 8	250 3
46 02	66 27	90 14	117 8	149 1	184 2	265 1
51 13	73 63	100 2	130 9	165 7	204 5	294 5
53 69	77 31	105 2	137 4	174 0	214 7	309 2
56 24	80 99	110 2	144 0	182 2	224 9	324 0
58 80	84 67	115 2	150 5	190 5	235 2	338 7
61 36	88 36	120 2	157 1	198 8	245 4	353 4
63 91	92 04	125 2	163 6	207 1	255 7	368 1
66 47	95·72	130 2	170 2	215 4	265 9	382 8
69 02	99 40	135 2	176 7	223 6	276 1	397 6
71 58	103 1	140 2	183 3	231 9	286 4	412 2
74 14	106 8	145 2	189 8	240 2	296 6	427 0
76 68	110 5	150 2	196 3	248 5	306 8	441 7

Ity [illegible] d.	1	1½	2	2½	3	3½	4
25	0511	1150	2015	3196	4602	6260	
[illegible]	1022	2301	4091	6392	9204	1 2[illegible]	1
75	1534	3450	6136	9588	1 381	1 878	2 4
00	2045	4602	8182	1 278	1 841	2 501	3 2
25	2556	5750	1 023	1 598	2 301	3 130	4 0
5	3067	6900	1 227	1 917	2 761	3 756	4
75	3578	8053	1 432	2 237	3 221	4 382	5
	4090	9204	1 636	2 557	3 682	5 008	6
25	4601	1 035	1 841	2 876	4 142	5 634	7 3
[illegible]	5112	1 150	2 015	3 196	4 602	6 260	8 1
5	5624	1 265	2 250	3 515	5 062	6 88[illegible]	9
	6135	1 381	2 454	3 835	5 522	7 512	9
25	6646	1 496	2 659	4 154	5 982	8 1[illegible]	10
[illegible]	7157	1 611	2 864	4 474	6 443	8 764	11 4
75	7669	1 726	3 068	4 794	6 903	9 390	12
	8180	1 841	3 273	5 113	7 363	10 0[illegible]	13
25	8691	1 955	3 477	5 433	7 823	10 64	13
[illegible]	9202	2 071	3 682	5 757	8 284	11 27	1
75	9713	2 186	3 886	6 077	8 744	11 89	15
	1 023	2 301	4 091	6 392	9 204	12 52	16
5	1 125	2 531	4 500	7 031	10 12	13 77	18
	1 227	2 761	4 909	7 670	11 01	15 0[illegible]	[illegible]
5	1 329	2 991	5 318	8 309	11 96	16 [illegible]8	21
[illegible]	1 431	3 221	5 727	8 948	12 88	17 53	22
[illegible]	1 533	3 450	6 136	9 588	13 81	18 78	24
	1 636	3 682	6 544	10 23	14 73	20 03	2[illegible] 1
[illegible]	1 738	3 912	6 954	10 86	15 65	[illegible]1 29	2[illegible]
	1 841	4 142	7 363	11 51	16 57	22 53	29 4
	2 045	4 602	8 182	12 78	18 41	25 04	[illegible]2
[illegible]	2 147	4 832	8 591	13 42	19 33	[illegible] 29	31
	2 249	5 062	9 000	14 06	20 25	2[illegible] [illegible]1	[illegible]
5	2 351	5 292	9 409	14 70	21 15	28 80	[illegible]
	2 454	5 522	9 818	15 34	22 09	30 05	[illegible]
5	2 556	5 753	10 23	15 98	[illegible]3 01	31 30	40
	2 658	5 983	10 64	16 62	[illegible]	3[illegible] 55	42
[illegible]	2 761	6 213	11 04	17 26	24 8[illegible]	[illegible]3 80	44
	2 863	6 443	11 45	17 90	[illegible] 77	[illegible]	4[illegible]
[illegible]	2 965	6 673	11 8[illegible]	18 [illegible]	[illegible]	[illegible] 31	47
	3 067	6 900	1[illegible] [illegible]7	19 18	[illegible]7 [illegible]1	[illegible]	49 [illegible]

-Of the Discharge of Pipes by Prony's Formula.

DIAMETER OF THE PIPE IN INCHES.						
5	6	7	8	9	10	12
GALLONS DISCHARGED PER MINUTE.						
1 278	1 841	2 504	3 272	4 142	5 113	7 [illegible]
2 556	3 682	5 008	6 544	8 284	10 23	14 [illegible]
3 834	5 523	7 512	9 816	12 43	15 34	22 [illegible]
5 113	7 363	10 02	13 09	16 57	20 45	29 [illegible]
6 390	9 205	12 52	16 36	20 71	25 57	36 [illegible]
7 668	11 05	15 02	19 63	24 85	30 67	44 1
8 947	12 88	17 53	22 95	28 99	35 79	51·[illegible]
10 23	14 73	20 03	26 18	33 13	40 91	58 [illegible]
11 50	16 57	22 54	29 45	37 28	46 02	66 [illegible]
12 78	18 41	25 04	32 72	41 42	51 13	73 [illegible]
14 06	20 25	27 54	36 00	45 56	56 25	80 [illegible]
15 34	22 09	30 05	39 27	49 70	61 36	88 [illegible]
16 62	23 93	32 55	42 54	53 84	66 46	95 7
17 89	25 77	35 06	45 81	57 98	71 59	103 1
19 17	27 61	37 56	49 08	62 13	76 69	110 4
20 45	29 45	40 06	52 36	66 27	81 81	117 [illegible]
21 73	31 29	42 57	55 63	70 41	86 94	125 [illegible]
23 01	33 13	45 07	58 90	74 55	92 03	132 [illegible]
24 29	34 97	47 58	62 17	78 70	97 14	139 [illegible]
25 57	36 82	50 08	65 45	82 83	102 3	147 [illegible]
28 12	40 50	55 09	72 00	91 12	112 5	162 [illegible]
30 68	44 18	60 10	78 54	99 40	122 7	176 7
33 23	47 86	65 10	85 08	107 7	132 9	191 4
35 79	51 54	70 11	91 63	116 0	143 2	20[illegible] 1
38 34	55 23	75 12	98 16	124 3	153 4	220 [illegible]
40 90	58·90	80 13	104 7	132 5	163 6	235 6
43 45	62 59	85 14	111 3	140 8	173 8	250 [illegible]
46 02	66 27	90 14	117 8	149 1	184 2	265 1
51 13	73 63	100 2	130 9	165 7	204 5	294 [illegible]
53 63	77 31	105 2	137 4	174 0	214 7	309 2
56 24	80 99	110 2	144 0	182 2	224 9	324 [illegible]
58 80	84 67	115 2	150 5	190 5	235 2	33[illegible]
61 36	88 36	120 2	157 1	1[illegible] 8	245 4	[illegible]
63 91	92 04	125 2	16[illegible] 6	207 1	255 7	[illegible]
66 47	95·72	130 2	170 2	215 4	265 9	[illegible]
69 02	99 40	135 2	17[illegible] 7	2[illegible]	2[illegible] 1	[illegible]
71 58	103 1	140 2	1[illegible] 3	2[illegible] 9	2[illegible] 4	412 [illegible]
74 14	106 8	145 2	1[illegible] 8	240 2	2[illegible]	4[illegible]
76 69	110 5	150 2	1[illegible] 3	24[illegible] 5	2[illegible]	441 [illegible]

Fig 14

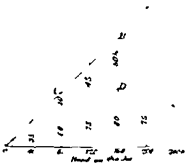


Fig 15

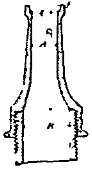
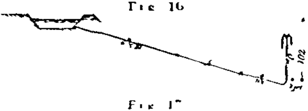


Fig 16



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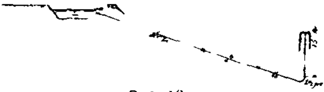

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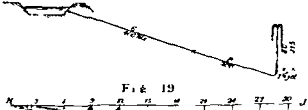

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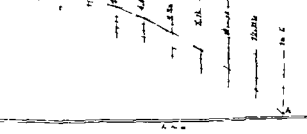

Fig 21

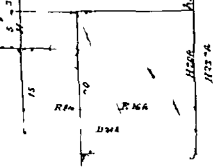

Fig. 23

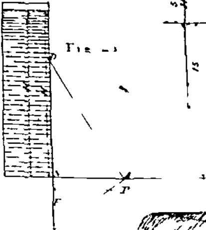

Fig 2

Fig 26

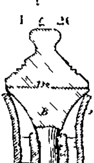

Fig 28

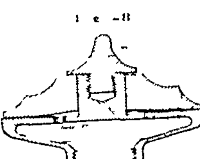

Fig 29

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